Language and Conflict Detection in the Development of Executive Function

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Dedication

For my parents, Regina and Wolfgang.

Abstract

The ability to override habit and exercise conscious control over thought, emotion and action, termed 'executive function' (EF), is a defining feature of human cognition. While a great deal is understood about the underlying cognitive processes and neural substrates of EF, much remains unknown about how it develops. Conflict monitoring theory has emphasized the role of prefrontally-based conflict monitoring and detection mechanisms in the activation of control processes. In contrast, Vygotsky's sociocultural theory of development suggests that experience, especially language, plays a key role in the emergence of higher-cognitive functions like EF from more basic cognitive processes. Both of these accounts have received broad empirical support, but they have never been considered in relation to one another. The current research tested the hypothesis that linguistic experience plays a key role in the development of conflict detection and EF. Study 1 tested the prediction that children who notice and focus on contrasting states of affairs show better EF. A significant relation was found between three-year-old children's EF and their tendency to focus on contrast indexed by their use contrastive negation on a novel picture book task, controlling for age and verbal IQ. In Study 2, a training experiment was conducted using a pre-post control group design in which three-year-old children were provided with linguistic experience involving the use of negation to contrast objects, attributes, and actions, and change in EF performance on a battery of EF measures was assessed. Results indicate that children exposed to contrastive negation showed greater increases in EF from pre- to post-test compared to children in two control conditions: an active control condition that experienced the stimuli without contrastive negation, and an inactive control condition in which children were read storybooks. Taken together, these findings provide new evidence that linguistic experience with contrastive negation used to highlight incompatibility may play a key role in the development of EF by increasing children's sensitivity to conflict, and possibly also by facilitating inhibition of task-irrelevant representations. Implications for theories of EF are discussed.

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A defining characteristic of human behavior is the ability to override habit in favor of current goals. This skill, termed ‘executive function’ (EF), is needed for goals ranging from those as simple as changing one’s route to work to more complex cognitive achievements such as reasoning and avoiding bias (Kahneman, 2011). EF is broadly defined as the conscious control of thought, emotion, and action and is supported by a suite of prefrontally-based cognitive processes, including maintaining and updating information in mind (working memory); suppressing responses or attention to information (inhibitory control); and flexibly switching between task demands (set-shifting) (Miyake, Friedman, Emerson, Witzki, Howerter, & Wager, 2000).

EF plays a key role in adaptive human functioning across the lifespan. It develops markedly in the early childhood years (Zelazo, et al., 2003; Diamond, 2013) and continues to develop into adulthood (Zelazo, Anderson, Richler, Wallner-Allen, Beaumont, & Weintraub, 2013). Childhood EF is associated with a range of cognitive abilities (mathematics, social reasoning, scientific concept formation; Mazzocco & Kover, 2007; Carlson & Moses, 2001; Hughes, 1998; Zaitchik, Iqbal, & Carey, 2013) and predicts several outcomes associated with success in adulthood (e.g., academic achievement, financial wellbeing, and health; Blair & Razza, 2007; Moffitt et al., 2011). Conversely, deficits in EF can have wide-ranging negative consequences for functioning and are implicated in numerous developmental disorders (Bechara, Damasio, Damasio, & Anderson, 1994; Pennington & Ozonoff, 1996; Biederman et al., 2004). Given the centrality of EF to human behavior, gaining insight into underlying mechanisms is a key research goal. Independent research traditions in cognitive neuroscience and cognitive developmental psychology have offered theoretical accounts of the nature of EF at different levels of analysis in an effort to advance knowledge in this domain.

EF and Conflict Monitoring Theory

One prominent account of EF in cognitive neuroscience is conflict monitoring theory, which posits that EF is triggered by conflict detection, made possible by a conflict monitoring system in the brain (Botvinick, Braver, Barch, Carter, & Cohen, 2001; Botvinick, Cohen, & Carter, 2004). Conflict monitoring theory proposes that control is recruited in response to the detection of conflict in information processing. Specific brain structures, namely the Anterior Cingulate Cortex (ACC), respond when there is competition among different response options, signaling conflict and triggering cognitive control processes. This leads to the resolution of conflict in information processing, evidenced behaviorally by more coordinated, controlled action in cognitively demanding contexts.

Conflict monitoring theory has garnered vast empirical support. There is evidence of ACC engagement across many behavioral contexts in which control is required. This includes tasks in which a prepotent response must be overridden; tasks that require selection from equally valid response options; and tasks that typically produce errors of commission. For example, in the classic Stroop task, in which subjects must name the color in which color words are typed (e.g., saying ‘red’ when the word ‘green’ is presented in red type), performance on incongruent trials in which there is a mismatch between color word and type is slower than congruent trials and is associated with ACC activation. Conflict monitoring theory explains this as resulting from the concurrent activation of incompatible, competing representations. The theory also offers an elegant explanation for the Gratton effect, the finding that there is less interference (as indexed by faster reaction times) on trials following an incongruent trial (Gratton, Coles, & Donchin, 1992). According to the theory, the incongruent trial triggers the activation of the control system, which helps to resolve conflict on subsequent trials.

Further support for conflict monitoring theory comes from work finding that errors of commission are associated with Error Related Negativity (ERN), which is EEG activity generated within the ACC. It is theorized that ERN occurs in response to transient response conflict due to activation of the error response and the belated correct response. Consistent with this view, larger ERN is associated with higher rates of corrective responding. Moreover, the N2, an EEG potential resembling the ERN, is associated with correct responses in contexts that induce response conflict (Botvinick, et al., 2004).

Limitations of Conflict Monitoring Theory as an Account of Executive Function

Conflict monitoring theory has explained and generated substantial empirical research in cognitive neuroscience. However, as a cognitive-neuroscientific theory, it explains the causal links between response competition, conflict detection and resolution exclusively in information processing and neurological terms, and thus is silent on whether or how conflict detection can be described at the psychological level. A psychological account would open the door to consideration of experiential factors that affect conflict monitoring and detection, and, in turn, the exercise of EF.

New research suggests not only that conflict detection can be described psychologically, but also that this level of explanation is most relevant to understanding the nature of EF. Desender, van Opstal, and van den Bussche (2014) found evidence that conflict is experienced subjectively and, moreover, that the subjective experience of conflict may be more important than the presence of response conflict itself in activating control. In their study, participants had to indicate the direction of a target arrow presented on a screen. Response conflict and experience of conflict were dissociated using a paradigm in which subjects were first presented with a prime that was masked (rendering it nearly invisible), followed by a target. Participants were warned about the invisible prime and were asked, after each trial, whether they thought there had been conflict between the prime and the target. Experience of conflict, but not response conflict, predicted greater adaptation on trials following incongruent trials (i.e., the Gratton effect), as would be expected if conflict detection and the activation of the control system crucially depend on subjective awareness (Desender et al., 2014).

Conflict monitoring theory is also silent on how conflict detection develops. Children clearly struggle with exercising executive function, particularly on tasks requiring response override (e.g., Carlson & Moses, 2001; Gerstadt, Hong & Diamond, 1994; Hughes, 1998; Zelazo et al., 2003). One possible explanation that might be offered in terms of conflict monitoring theory is that children simply lack the capacity to detect and resolve conflict, which may develop with increases in ACC functionality. Research indicates that functional organization of the region of ACC linked with conflict detection develops into late childhood and adolescence (Eshel, Nelson, Blair, Pine & Ernst, 2007;

Kelly et al., 2009), which is consistent with broader findings concerning prefrontal cortical development and its protracted course (Diamond, 2002; Casey, Giedd, & Thomas, 2002; Gogtay, et al., 2004). However, while this account may be true, it is relatively impoverished as an explanation insofar as it does not imply or explicate any role for environment or experience. It is well established that EF improves dramatically across childhood, which has been theorized to occur through interactions between experience and brain development (Zelazo, Carlson, & Kesek, 2008), a view that is supported by a growing body of empirical research (e.g., Bernier, Carlson, Whipple, 2010; Diamond, 2012; Hammond, Mueller, Carpendale, Bibok, Liebermann-Finestone, 2010; Hostinar, Stellern, Schaefer, Carlson, & Gunnar, 2012; Talwar, Carlson, & Lee, 2011). In addition to what is now accepted regarding the role of neural plasticity in cognitive development (Nelson, 1999), this suggests that experience likely plays a role in the development of the ACC, conflict detection, and EF.

Vygotsky's Sociocultural Theory and the Role of Language in the Development of Executive Function

The notion that experience is key to the development of EF has a long history, going back to the Russian psychologist Lev Vygotsky (1962). On Vygotsky's view, higher cognitive functions are constructed out of more basic ones via 'psychological tools' that are culturally transmitted. These psychological tools begin as *inter*psychological relations, such as interpersonal communication, that are later internalized as *intra*psychological functions. This internalization process is akin to the appropriation of a material tool, utilized to make possible more sophisticated cognition and action that is adaptive within a particular cultural environment. A specific example of this is self-regulation, which Vygotsky posited is verbally mediated and is social in its origins. At first, children's ability to effectively monitor and guide their own actions is very limited, and is supported in the moment by the speech of adults. Over time, children come to use their own external speech to take on this self-regulatory function, a practice termed 'private speech'. Private speech is theorized to be an intermediate stage in the development of self-regulation via self-directed speech, later going "underground" as internal verbal self-direction or thought, termed 'inner speech'. This inner speech is qualitatively different from social speech, being highly condensed.

This theoretical perspective has inspired and shaped the focus of much of the vast empirical literature examining the relation between language and EF in development (see Cragg & Nation, 2010, for a review). During Vygotsky's time, Russian neuropsychologist Alexander Luria (1959; 1961) and others examined Vygotsky's ideas experimentally, testing the general hypothesis that higher-order control processes are verbally mediated. More recently, longitudinal studies have found that parental verbalization aimed at helping guide children's task performance (referred to as 'scaffolding') predicts EF performance in early childhood (Landry et al., 2002; Hughes & Ensor, 2009), with some evidence that the relation is mediated by child verbal ability (Hammond et al., 2012). Research on the self-regulatory function of private speech has found relations between private speech and performance on tasks requiring planning, selective attention, and resisting temptation (Behrend, Rosengren, & Perlmutter, 1989; Carlson & Beck, 2009; Fernyhough & Fradley, 2005; Winsler, Diaz, & Montero, 1997).

Research examining the role of inner speech in task-switching has found that articulatory suppression interferes with flexible switching (Emerson & Miyake, 2003), and that children's performance is disproportionately impaired under articulatory suppression compared with adults (Kray, Eber, & Karbach, 2008). Another line of research has investigated the development of verbal rehearsal as a maintenance strategy in support of working memory span, finding that at around seven years of age, children start using covert rehearsal to guide performance on short-term memory span tasks, as evidenced by lip movement during task completion (Flavell, Beach, & Chinsky, 1966) word length and phonological confusion effects (Gathercole, 1998), and impaired performance under articulatory suppression (Tam, Jarrold, Baddeley, & Sabatos-DeVito, 2010). More generally, there are numerous correlational studies that have found associations between children's verbal skills and EF (e.g., Carlson & Moses, 2001; Hughes, 1998; Hongwanishkul, Happaney, Lee, & Zelazo, 2005). In sum, there is no shortage of evidence of central role for language in the development and exercise of EF across the lifespan.

There is also evidence that linguistic experience may provide a psychological tool for the development of higher cognitive skills in another core domain of human cognition, theory of mind. Work by de Villiers and de Villiers (2000) suggests that skill in representing that others can have false beliefs is dependent on the mastery of certain syntax, namely sentential complementation, in which verbs (such as mental state verbs) are combined with complete sentences to express a proposition (e.g., *Sally thought Paul went to the store)*. Findings from a longitudinal study indicated that skill in understanding sentential complements predicted false belief performance, controlling for other language skills (de Villiers & Pyers, 2002). A subsequent training study found that training in the syntax of sentential complements led to improvement in performance on false belief tasks, as did training in perspective taking discourse (Lohmann & Tomasello, 2003).

The extensive empirical support for the Vygotskian view of the integral role played by linguistic experience in the development of higher cognitive function such as EF, and the equally impressive support for the role of conflict detection in the activation of control processes, suggests that these two perspectives might be fruitfully integrated to gain deeper insight into how EF develops. A key question that arises is what role might language play in the development of conflict detection?

Language, Consciousness, and Cognitive Complexity in the Development of Executive Function

Ideas about what kind of linguistic experience might be relevant to detecting conflict are suggested by another contemporary theory that brings together cognitive neuroscience and developmental perspectives, the Cognitive Complexity and Control Theory – Revised (CCC-r; Zelazo et al., 2003). CCC-r posits that age-related increases in the complexity of rules that children can construct via inner speech lead to increases in EF, given that more complex rules are needed to adequately represent task demands and guide behavior. This idea can be illustrated by considering developmental change in children's performance on the Dimensional Change Card Sort (DCCS; Frye, Zelazo, & Palfai, 1995; Zelazo, 2006), a widely used measure of cognitive flexibility in early childhood. Children first sort bivalent test cards (e.g., red rabbits and blue boats) according to one dimension (e.g., by color) for several trials, and are then instructed to switch to sorting the same cards according to a new set of rules (e.g., by shape). Three-year-olds typically perseverate and continue to sort the cards according to the initial rule set. This pattern occurs despite children being informed of the new rules before every trial and showing evidence that they know where the cards ought to go (Zelazo et al., 1996). By contrast, typically developing 4- and 5-year-olds experience little difficulty switching to sorting by the new rules. According to CCC-r theory, successful switching requires the formulation and use of a higher-order rule for switching between dimensions (e.g., If it's the color game, then the red ones go here and the blue ones go there; but if it's the shape game, then the rabbits go here and the boats go there).

The Levels of Consciousness (LOC) model (Zelazo, 1999; Zelazo, 2004) extends this account by further proposing that the capacity to construct higher order rules is achieved through developmental increases reflection, corresponding to the iterative reprocessing of information via neural circuits in hierarchically arranged regions of PFC (Cunningham & Zelazo, 2007; Bunge & Zelazo, 2006). On this model, age-related increases in the degree of reflection that can be attained affects the quality of experience a child can have, and how they represent and respond to situational demands. For example, a young three-year-old who can only achieve a relatively low LOC may only be able to view bivalent stimuli in the DCCS task (e.g., red rabbits and blue boats) alternately in terms of one or the other dimension (i.e., shape or color), whereas older children who can achieve a higher LOC can reflect that there are multiple ways to construe the same bivalent stimuli. Being able to view the same stimuli from multiple perspectives is, on this model, key to considering the rules corresponding to each sorting dimension in contradistinction (i.e., shape game versus color game) and integrating them under one higher-order rule.

According to the LOC account, language likely plays a critical role in helping children achieve a higher LOC. One way is through the labeling of one's subjective experience, which, on this account, allows it to become an object of consciousness that can then be considered in relation to other objects of consciousness and used in representations to guide action (Zelazo, 2004). In support of this account, research by Jacques and Zelazo (2005) found that when three-year-olds were given the opportunity to label their classifications on a task in which multiple classifications of a small set of stimuli were possible, they showed more cognitive flexibility and were better able to consider other ways of classifying the stimuli.

The foregoing suggests that other kinds of linguistic experience could help make the experience of conflicting information more conscious. For example, experience with language that highlights incompatibility between things could increase the likelihood that one would become conscious of incompatibility when presented with it. In the context of EF, such linguistic experience could facilitate awareness of incompatibility between conflicting rules, and enable the integration of the rules under a higher-order rule. Importantly, whereas conflict monitoring theory proposes a cognitive neuroscience account that response conflict generates a signal that cues greater activation of control, CCC-r theory and the LOC model provide grounds for a complementary psychological account.

There is some empirical evidence that linguistic experience may induce changes in conflict detection in children via increases in reflective capacity. Espinet, Anderson, and Zelazo (2013) found that verbally encouraging young children to reflect during the completion of an executive function task resulted in greater improvement in performance at a subsequent session and a reduction in the N2, an ERP component that is considered a neural marker of conflict detection. Espinet et al. theorized that reflection training would trigger reflective reprocessing of information in prefrontal cortex (Cunningham & Zelazo, 2007), allowing for the formulation and maintenance of higher- order rules in working memory. This study indicates that verbally training children to reflect on what they are doing in the context of needing to use EF helps them to succeed in using it, likely by enhancing the ability to resolve conflict.

Further evidence that exposure to language that emphasizes incompatibility between rules aids EF comes from a meta-analysis of the DCCS (Doebel & Zelazo, under review). In this study, it was found that verbally emphasizing the incompatibility between the games at the introduction of the post-switch phase was associated with higher rates of switching. In the standard protocol, the post-switch phase is introduced by announcing a new game, contrasting the two games explicitly, followed by introducing and repeating the new rules: “Now we’re going to play a new game. We’re not going to play the color game anymore. We’re going to play the shape game. In the shape game, all the rabbits go here [pointing to the tray on the left], and all the boats go there [pointing to the tray on the right]. Remember, if it’s a rabbit, put it here, but if it’s a boat put it there,” (Zelazo, 2006). Other researchers have used language to further highlight the contrast between the conflicting rules in several additional ways, such as further emphasizing which game is *not* being played ("We're not playing the color game anymore, no way"; Munakata & Yerys, 2001), stating explicitly which rules are *not* to be used (e.g., Bohlmann & Fenson, 2005), and noting the novelty and distinctiveness of the new game ("The shape game is *different*." e.g., Munakata & Yerys, 2001; Kloo & Perner, 2005). In several conditions the post-switch instructions explicitly emphasized that the new game was "different", which may have prompted children to reflect on the two sets of rules and their incompatibility, which in turn may have allowed them to represent the rules in an integrated fashion. Taken together, these studies suggest the possibility that linguistic experience accrued on a more protracted scale, outside of the immediate EF context, may help children become conscious of conflict.

Contrastive Negation, Conflict Detection, and Executive Function

The present research is guided by the hypothesis that experience with language that highlights incompatibility between things (e.g., objects, events, actions, goals) may lead to increases children's conscious awareness of conflict among rules, prompting them to construct hierarchical representations to coordinate the rules and guide action, which relies on anterior regions of PFC.

What kind of linguistic experience could fill this role? Two or more statements are said to be incompatible if they cannot be true at the same time (e.g., the statements 'It is raining' and 'It is not raining'). Similarly, two or more properties are incompatible if they cannot simultaneously belong to one object (e.g., the property of being round versus being square). Incompatibility can also be a property of actions (e.g., running versus walking) and events (e.g., going to the store versus staying home in bed). One linguistic device that may facilitate representation of incompatible information is contrastive negation. This function of negation serves to contrast information, denying one proposition and entailing another in the form *Not X; Y* (Bloom, 1970; McNeill & McNeill, 1968). Bloom identified contrastive negation as a relatively late acquired use of negation, emerging between three and four years of age, in which the child must be able to hold two propositions in mind (e.g., "That's not dolly's; that's mines," Bloom, 1970). Children likely acquire an understanding and ability to use contrastive negation through experience in various linguistic contexts, such as antonyms use (e.g., "Not up; down") and in the contrasting of actions (e.g., "Don't play with your toys; brush your teeth"), concepts ("That's not red, it's blue") and even rules (e.g., "Don't run inside; walk," or "The green shapes don't go in that pile; they go in this pile").

In line with Vygotsky's view, experience with contrastive negation may furnish children with a psychological tool that allows them to represent and notice incompatibility between rules. For example, children who have just been introduced to the post-switch rules of the DCCS might be in a better position to spontaneously notice conflict between the old and new rules, given experience with contrastive negation. For example, upon hearing the new rules they may represent "*Not shape; color*," instantiating conflict detection and prompting construction of a complex representation that integrates and coordinates the rules. Experience with contrastive negation may also provide the very language needed for complex representation of the rules in self-directive inner speech (e.g., *"Color; not shape→red goes with red…").*

Preliminary Evidence of a Role for Contrastive Negation in Conflict Detection

There is some preliminary empirical evidence that exposure to contrastive negation may aid EF by enhancing conflict detection. In an experimental study with three-year-old children (M_{age} = 3.51 years), the labeling procedure in the DCCS was modified to enhance emphasis on the incompatibility between the two sorting games embedded within the task (Doebel & Zelazo, in preparation). In the control condition, test cards were labeled by the experimenter by both dimensions, both in the pre-switch and post-switch phases (e.g., “Red. Rabbit,” when sorting by shape). In the modified version, the labels in the post-switch phase were stated using contrastive negation (e.g., “*Not* red; rabbit.”) It was hypothesized that using contrastive negation to emphasize incompatibility between the dimensions would help children notice conflict and activate control, leading to more flexible switching. The results supported this hypothesis, with children sorting significantly more cards correctly in the contrast label version (M =2.67, SD = 0.56) than they did in the standard label version (M = 2.35, SD = 0.49), t(22) = , p = .014. Individual patterns indicate that of the 23 children tested, six children only passed the contrast label version, two passed only the standard version, and three passed both versions. This pattern suggests further that the contrast label version was easiest for children. While this evidence is suggestive, this study at best shows that *within* the context of an EF task, contrastive negation can aid performance. Further research is needed to test the hypothesis that exposure to contrastive negation in ordinary linguistic contexts provides children with a framework to notice and represent conflict.

The Current Research

The two studies reported here test a developmental, psychological account of the relation between conflict detection and EF by examining whether experience with contrastive negation provides a linguistic representational tool that facilitates conscious awareness of conflict. In Study 1, an exploratory investigation was undertaken to assess whether preschool children's spontaneous tendency to focus on contrasting states of affairs and use negation contrastively is related to EF, controlling for general verbal ability and age. In Study 2, a training experiment was conducted to test whether familiarizing children with contrastive negation would improve performance on conflict EF tasks.

Study 1

If conflict detection plays a key role in the exercise of EF, then children who spontaneously notice and focus on contrasting states of affairs (i.e., involving objects, events, or actions) may be in a better position to notice conflict between competing rules and engage EF than children who do not notice or focus on contrast. In this study, a novel task was created to measure children's tendency to notice and attend to contrasting states of affairs, the Focus on Contrast Task (FCT). Children also completed measures of conflict EF as well as a measure of verbal ability. It was hypothesized that focusing on contrast would be associated with better EF, controlling for age and verbal ability.

A secondary aim of Study 1 was to pilot test the use of the three EF measures to assess their suitability for use in a training study (Study 2) and to determine what adjustments, if any, were needed to maximize their usefulness as measures of change in EF across a one-week interval.

Method

Participants

Fifty-one three-year old children (M_{age} = 3.73 years; SD = 0.15; 24 boys) were recruited from a database of families living in Minnesota who had volunteered to be contacted to participate in research. Ninety-one percent of participants were white, 98% were non-hispanic, and 77% had a college or higher level of education.

Procedure

Children were seated at a small table across from the experimenter in a plainly decorated room. The experimenter engaged in small talk with the child in the presence of the parent to help the child become comfortable. Once the child indicated that they were ready to participate, the experimenter proceeded with the tasks to be completed in a fixed order: the FCT, the EF measures and the verbal IQ test, all of which are described in detail below. The EF tasks used in this study were chosen because they were expected to generate response conflict in children, in which two competing, incompatible responses are activated and one of these responses (the prepotent response) needs to be overridden.

Materials

Focus on Contrast Task. This task was designed to measure children's tendency to attend to contrasting states of affairs or situations depicted in pictures on a page. The experimenter pointed to one of four pictures on a page and expressed a proposition about it (e.g., "The bear is in the box"). Children were asked to "point to one that is different," and explain their choice. The three remaining pictures represented: 1) a different but similar situation (e.g., a bear in a box in a slightly different position); a contrasting situation (e.g., an empty box); and an unrelated situation (e.g., a tree). The complete list of items used in the FCT can be found in Table 1. Children completed ten trials and two indices of focus on contrast were derived from the task: the number of trials on which children pointed to the contrasting picture, and the number of trials on which children used negation contrastively by verbally negating the initial proposition (e.g., “There’s *no* bear in the box!”, “Not a bear in a box,” or “No bear”). It was predicted that the two indices would be correlated, which would provide assurance about the validity of the measure. Moreover, the verbal metric was expected to provide insight into whether focus on contrast is verbally mediated. In addition, there was the possibility that the verbal measure might be more sensitive, given that children might occasionally point to the contrasting picture for reasons other than that it contrasted with the target, and, conversely, they might verbally negate the proposition stated by the experimenter but fail to point to the picture that *best* represents contrast.

Modified EF Scale (Carlson, 2013). The EF Scale is an updated, expanded version of the Conflict Scale (Beck, Schaefer, Pang & Carlson, 2011), which in turn was designed as a scaled expansion of the DCCS (Frye, Zelazo, & Palfai, 1995; Zelazo, 2006). On the DCCS, children are instructed to sort cards by one dimension (e.g., shape) for 5 trials, and then are instructed to switch to sorting by a new dimension (e.g., color). The EF Scale requires children to complete discrete card-sorting tasks like the DCCS at different levels of difficulty, to ascertain the most advanced level that a child can complete. A given child would have to complete a minimum of two separate card sorts so that the highest level that they could pass could be determined. The task described here is modified from Carlson (2013) by the addition of a level intermediate between the standard version in which the relevant dimension is labeled by the experimenter, and the mixed level. In the intermediate level, both dimensions on the test card were labeled by the experimenter, which research has found makes the task more difficult (Doebel & Zelazo, 2013; Doebel & Zelazo, under review). All children began the task at level four. If they did not succeed at this level, they next completed level three and continued downward until they passed a level or failed to pass the lowest level in the task (level one). Likewise, children who passed level four then completed level five and continued upward until they reached a level they could not pass. The task was composed of eight levels (see Appendices A and B for full description of each level and scripts that were used for each card sort):

Day/Night Stroop (Gerstadt, Hong, & Diamond, 1994). The Day/Night Stroop is, as the name suggests, modeled on the adult Stroop task that has yielded much empirical support for conflict monitoring theory. Instead of exploiting the dominant response to read type, the Day/Night Stroop exploits pre-established associations between words that then need to be overridden in the task. In this task, children are presented with cards that depict a yellow sun or a white moon against a black background. To warm up, the experimenter showed the sun card to the child and asked, “Do you know when the sun comes up?” This procedure was repeated for the moon and then the experimenter said, “We’re going to play a game where when I show you a picture of the sun, you say ‘night’, and when I show you a picture of the moon, you say ‘day’.” Two practice trials with corrective feedback were administered. Once the child completed two trials correctly, the experimenter proceeded with 16 test trials on which no corrective feedback was provided. Alternate responses such as “morning time” and “dark” were scored as correct so long as they were consistent with the rules of the game (e.g., saying “dark” to the sun card).

Hand Game (Hughes, 1998). In this task, originally developed by Luria (Luria, Pribram, & Homskaya,1964), the experimenter first makes one of two hand gestures (fist or point) and children are instructed to copy/make the same the gesture (imitation phase). To introduce the task the experimenter said, demonstrating the gestures, “We are going to play a game where I make a shape with my hand and you make the same shape as me. So if I make a fist, then you make a fist, and if I make a point, then you make a point. Okay? Let’s try… What do you do if I make a fist? …And if I make a point?” Once the child had correctly imitated each gesture consecutively, the experimenter proceeded with the test trials. Children needed to complete six consecutive imitation trials correctly or a total of 15 trials before proceeding to the next phase of the task. Once this criterion was reached, the experimenter said, “Now, we are going to play a different game where you make a different shape than me. So if I make a point, then you make a fist. And if I make a fist, then you make a point. Let’s try. What do you do if I make a fist? ... And if I make a point?” Children received corrective feedback if they did not complete the first two trials correctly, which were then counted as practice trials. Once two trials were completed correctly, those trials were counted as test trials and 13 more trials were completed for a total of 15. No corrective feedback was provided on test trials and self-corrections (i.e., partial imitation gestures that were modified to anti-imitation gestures) were coded as errors.

Peabody Picture Vocabulary Test (Dunn & Dunn, 2007). This task was included as a measure of verbal IQ, to control for the possibility that children who focus on contrast are generally more advanced than children who show other patterns on the FCT. In this task, children are shown a set of four pictures and provided with a word that corresponds to one of the pictures. The participant is asked to point to or say the number of the picture that best corresponds to the word. Children must respond incorrectly to 8 items in a given 12-item set before the task is discontinued. Children's scores reflect the number of items to which they responded correctly minus their total errors.

Results

First, performance on the FCT is summarized, followed by analyses of relations between performance on this task and the EF tasks. Children showed variability in their performance on the FCT. Their tendency to select contrasting items ranged from 0 to 10, with a mean of 4.61 (SD = 2.54) and mode of 6. Similarly, children varied in the extent to which they used contrastive negation when explaining their selection, ranging from 0 to 10; however, as evidenced by the modal response of zero, a fair number of children did not use contrastive negation (see Figures 1 and 2 for histograms depicting performance on the task). Nevertheless, contrast selection and verbal responses corresponding to contrastive negation were highly correlated, $r(44) = .63$, $p < .001$.

To gain a better sense of the expected developmental trajectory of performance on this task, data were collected from 11 adults and it was found that the mean number of contrasting items adults selected was 6.0 (*SD* = 3.49), and the mean number of times they used contrastive negation was 3.90 (*SD* = 3.20). When the two indices were combined to create a composite measure of focus on contrast, the difference between children's (*M* = 7.43, *SD* = 4.42) and adult's (*M* = 9.72, *SD* = 5.19) performance was trending towards significance, $t(53) = 1.49$, $p = .14$, suggesting that there may be a developmental trend towards increasing focus on contrast.

Table 2 shows the raw correlations among the measures used in this study. The EF tasks were not correlated, so analyses were conducted separately for each task. Performance on the EF scale was associated with selection, $r(49) = .28$, $p = .05$, and, to a stronger degree, contrastive negation, $r(42) = .41$, $p = .007$. Performance on the other EF tasks was not significantly correlated with performance on the FCT. After accounting for age and verbal IQ, the relation between performance on the EF scale and contrast selection was no longer significant, $r(42) = .19$, $p = .23$. This is likely in part due to the loss of power with fewer participants completing all three relevant measures. On the other hand, the relation between performance on the EF scale and contrastive negation remained significant after controlling for age and verbal IQ, $r(35) = .39$, $p = .018$.

Discussion

The current study aimed to explore whether focus on contrast was related to EF skills in young children, as an initial test of the central hypothesis that linguistic experience that emphasizes contrast may help children notice conflict in contexts demanding EF. The study found preliminary evidence that children who tend to focus on contrasting information and use contrastive negation perform better on a widely used measure of executive function, controlling for age and verbal ability. This supports the idea that the tendency to notice and focus on contrast emerges through linguistic experience that directs children's attention to contrast, making it more salient in the environment. This is consistent with the finding that children's verbalizations expressing the contrasting proposition was a better predictor of their performance on the EF scale than their picture selections.

It is also worth noting that age was marginally associated (trending toward significance) with contrastive negation on the FCT. One interpretation is that, with age, children acquire linguistic experience (e.g., involving contrastive negation) that increasingly disposes them to take note of contrasts among objects, and actions. Children's tendency to focus on contrast was generally lower than that of adults, suggesting that noticing and focusing on contrast develops. Nevertheless, this study falls short of allowing clear conclusions to be drawn, given the use of a correlational design and the measurement of a limited number of covariates. It is possible that some other unmeasured variable explains the relation between the FCT and EF scale, or that the reverse causal relation might reflect reality, in which stronger EF leads to greater ability to focus on contrast.

This study did not find a relation between the other EF tasks and focus on incompatibility, which may not necessarily reflect a lack of relation but rather some issues with the EF measures used. Both the Day/Night Stroop and the Hand Game had some issues with ceiling effects, which may have reduced variability needed to detect relations with the FCT. On the Day/Night Stroop, 12 of 47 (26%) children who completed the task were at or near ceiling, completing 14 or more trials without error. On the Hand Game, 37% (15 out of 41 participants who completed the task) were at or near ceiling on the task, completing 12 or more trials without error.

Detection of variability and individual differences may also have been limited on the EF scale. Zero out of 49 children who completed the task were able to pass level six (mixed), whereas 15 children passed level five (in which both dimensions are labeled). This suggests a gap in the scale. That is, given this distribution, it seems plausible that some of the children who passed level five could have also passed a level intermediate between levels five and six. This added variability would be useful in measuring individual differences and identifying relations with other variables.

In summary, Study 1 found promising results suggesting a relation between focus on contrast and EF in young children, but was limited by its design and some aspects of the EF measures. Study 2 was designed to provide a stronger test of the overarching hypothesis that linguistic experience involving contrastive negation plays a key role in the development of EF by facilitating spontaneous verbally-mediated representations contrasting incompatible rules, instantiating conflict detection and engagement of control; and providing the linguistic framework for a complex representation of the rules needed to guide action. To facilitate detection of subtle variations and changes in EF skills, focused, empirically guided modifications were made to EF tasks to enhance their usefulness for a training study.

Study 2

Study 2 builds on the findings of Study 1 and tests the hypothesis that exposure to contrastive negation used to highlight incompatibility between things may help children notice conflict and engage EF more effectively than children who do not receive such linguistic experience. Study 2 tests this hypothesis via a training study in which language was used to highlight incompatibility between object categories, attributes, and actions, and change in performance on a battery of EF tasks from pre- to post-test was examined. Affirmative findings would provide support for the idea that language plays a role in the development of conflict detection, and, in turn, EF.

Method

Participants

60 3-year-old children (M_{age} = 3.70 years, *SD* = 0.08; 26 boys) were recruited using the same participant database as in Study 1. Six additional participants were excluded due to uncooperativeness that prevented completion of the primary study tasks. Among the 60 participants who completed the two sessions, three did not complete the EF scale, three did not complete the Day/Night Stroop, and five did not complete the Hand Game.

Design and Procedure

A pre-post control group design was used in which children were randomly assigned to one of three conditions, with 20 children per condition. In the contrastive negation training condition, children were exposed to contrastive negation used to highlight incompatibility between objects, attributes, and actions. In the active control condition, children were exposed to the same stimuli but without contrastive negation. In the inactive control condition, children were read two storybooks and did not receive any exposure to contrastive negation or stimuli highlighting incompatibility.

Children completed the study across two sessions. At the first session, they first completed an EF pre-test battery, followed by the first of two training sessions. At the second session, children completed a second round of training, followed by the EF post-test, manipulation check, and verbal IQ test. Children in the inactive control group were read two storybooks at each session. The duration of each session was approximately 30 to 45 minutes.

Materials

EF Scale (Carlson, 2013). The EF Scale was administered as in Study 1 but with two modifications to address the concerns regarding variability and improving the likelihood that the training, if efficacious, would induce detectable movement in a positive direction on the scale. All levels remained the same except that the labeling procedure for level five was modified and a new, more challenging level was introduced after this level. In the conflicting label version, children received relevant labels in the pre-switch phase and conflicting labels in the post-switch phase (e.g., 'Here is a red one,' when playing the shape game). This labeling procedure has been demonstrated to be at least as challenging as the 'both label' version (Doebel & Zelazo, 2013) and was meant to reduce the chances that the label might inadvertently cue the relevant dimension during the post-switch phase (i.e., when labeling both dimensions, one part of the label *is* relevant). The new level (now level six) was intended to further reduce the salience of the post-switch rules and thereby make the task more challenging than level five but not quite as difficult as the ‘mixed’ version (designated as level seven in the current study). This version was modeled on Honomichl & Chen (2010), in which children sorted by shape in the pre-switch phase and sorted by the above/below relation in the post-switch phase. See Appendix 3 for more detail regarding these levels of the task. Level numbers were adjusted accordingly for the purpose of scaled scoring.

Day/Night Stroop Task (Gerstadt, Hong & Diamond, 1994). The Day/Night Stroop was administered as in Study 1 with the exception of the number of test trials. Four additional test trials were added in an effort to increase task difficulty and remove ceiling effects. Gerstadt et al. (1994) note that children tend to perform worse on later trials, so the addition of trials was expected to lead to more errors among some children.

Hand Game (Hughes, 1998). The Hand Game was administered as in Study 1 with the exception of the number of imitation trials. To reduce the possibility of ceiling effects that were seen in Study 1, all children completed 15 imitation trials before proceeding to the anti-imitation phase, in which a further 15 (anti-imitation) trials were administered.

Manipulation check. The Focus on Contrast Task (FCT) was used as a manipulation check for this study. It was expected that if the contrastive negation training helped children to represent contrasting information, then they should be more inclined to select contrasting items and use contrastive negation on the FCT. A few of the task items were changed to reduce the possibility that children were selecting well-learned opposites (e.g., sad/happy, pretty/ugly) versus focusing on contrast per se. Other items were changed and added to enhance the variability to the set of items to ensure that children’s responses reflected their general tendency to focus on contrast. The new task was composed of 12 items instead of 10, which was expected to add power and potentially increase variability in responses to the task on each derived index, contrast selection and contrastive negation. See Table 3 for the items used in the task.

Peabody Picture Vocabulary Test. The PPVT was administered as in Study 1 and was the final task completed at the second session.

Training protocol. Children completed one of three protocols, depending on condition assignment: contrastive negation training, stimuli only, and storybook. These three groups represent the experimental, active control, and passive control conditions, respectively. The protocols described below were repeated in full at the second session.

Contrastive negation training. Children assigned to this condition completed five short tasks in which they were familiarized with contrastive negation, that is, negation used to contrast pairs of situations, attributes, objects, and actions. The tasks were designed to be structurally diverse to increase the likelihood that the training would transfer to new contexts. The word *different* was used in conjunction with contrastive negation in these tasks to further highlight incompatibility. The tasks are briefly described below. See Appendix 5 for the complete training protocol.

Negation used to contrast pairs of objects, attributes and actions. In this task children were presented with ten sets of three pictures. In each set, there was a target picture and two pictures that represented either compatible (matching) or incompatible/contrasting objects, attributes, and actions. The experimenter pointed to a target picture and said, for example, “This one is round. Now can you show me one that is different, that is not round?" After the child made their selection the experimenter said, "Good, this one is not round. It's different." Errors were corrected (e.g., "Actually, this one is not round. It's different"). The experimenter responded minimally to any spontaneous reference to the matching picture (e.g., "Okay, let's look at some more pictures").

Negation used to contrast categories. In this task, children were told that they were going to be shown pictures and the experimenter was going to ask about them and would sometimes say things that were not right, and that the child should tell the experimenter if she said something wrong. Children were then presented with a series of pictures of category exemplars, one at a time, and were asked about them. For example, children were shown a picture card with an illustration of a banana and were asked, "Is this an apple?" After a response was provided (children were expected to say no), the experimenter said, "No, this is not an apple. It's different. It's a banana." On half of the pseudo-randomly ordered trials the experimenter's label matched what was on the card (e.g., "Is this a banana?" when a picture of a banana was presented). Children completed 12 trials of this task per session.

Negation used to contrast associated versus non-associated items. In this task, children were presented with six picture cards on a table in no particular arrangement. Four of the cards formed associate pairs, and two were unrelated. The experimenter informed children that together they were going to find ones that "go together". The experimenter then pointed to one of the cards and asked the child what was on the card, and then did the same with the associated card and asked the child whether the cards went together. The experimenter then said, “Yes, these go together,” before moving on to the next pair. If the child erred, the experimenter corrected by saying, “Actually, they *do* go together.” The final pair discussed was the unrelated pair. In this case, after the experimenter received the child’s response regarding whether the pictures go together, she said, “No, they do not go together; they’re different.” Children completed three trials.

Negation used to contrast dimensional values. In this task, children were presented with a set of 16 randomly distributed small shapes or colors on an 8 by 12 inch page, some of which were to be circled. For example, children were presented with a page depicting numerous exemplars of three different shapes: hearts, zigzags, and stars, and were asked to circle the ones that “are not hearts; that are different.” On each page there were eight shapes or colors that needed to be circled (e.g., four zigzags and four stars), and eight irrelevant shapes or colors (e.g., eight hearts). On a different trial, children were presented with a page of 16 dots in three colors: blue, purple and yellow and asked to circle the ones that were not blue. The experimenter repeated the instructions after every other item the child circled.

Negation used to contrast goals. In this task, children were presented with five pictures, each presented on a separate page in a “picture book” and were told that the experimenter was going to tell them about what was happening in the picture and then would ask a question. The question was asked in order to ensure the child was paying attention to what the experimenter was saying. In each of five pictures, the experimenter used a narrative to emphasize incompatibility between two courses of actions. For example, the experimenter presented a picture of a child with her mother at the grocery store and said, “Jane and her mom could get red apples or they could get green apples. Jane is about to pick the red apple and her mom says, ‘We are not getting the red apples, we are getting something different.’” Children were then asked, “What did Jane’s mom say?” and their responses were recorded.

Stimuli only condition. In this condition children were exposed to the exact same stimuli that were used in the negation training condition, but were not exposed to contrastive negation. In task 1, children were asked to label the pictures one by one with the experimenter facilitating. In task 2, children were asked to find the picture that matches the target. In task 3, the experimenter asked children for the name of what was depicted on the card. In task 4, children were instructed to circle a given shape (e.g., “Circle all the hearts.”). In task 5, the narratives were modified so that they did not make any reference to incompatible actions. See Appendix 5 for the complete protocol.

Storybook condition. In this condition children were read two storybooks at each session. Different books were read at each session to ensure that children did not become bored. The four books that were read were *Go Dogs, Go*, *The Big Road Race*, *Are You My Mother?* and *Flap Your Wings*. This condition controlled for the possibility that children might spontaneously notice incompatibility during exposure to the stimuli in the active control condition, even without language, which could in turn facilitate conflict detection and EF. Indeed, some children in the Stimuli Only condition did make spontaneous comments to this effect when viewing the stimuli.

Results

Preliminary analyses revealed no effects of gender (*t*s <.95, *p*s >.35) or experimenter (*F*s <1.18, *p*s > .327), thus these variables were not included in subsequent analyses. Scores on the vocabulary measure did not differ significantly by group, $F(2, 57) = 1.18$, $p = 0.31$, confirming the effectiveness of random assignment and suggesting no a priori differences between groups in verbal IQ. Table 4 shows bivariate correlations between all measures and Table 5 shows mean performance on each measure by condition.

Performance across groups on the manipulation check (FCT) indicates that contrastive negation training was successful in enhancing children's focus on contrasting information. Two one-way Analyses of Variance (ANOVAs) were performed with contrast selection and use of contrastive negation as the dependent variables, and condition as the independent variable. Both of these ANOVAs were significant, $F(2, 57) = 23.48$, $p < .001$, and $F(2, 57) = 16.68$, $p < .001$. Post hoc analyses using the Bonferroni correction indicate that children in the contrastive negation training group ($M = 6.90$ $SD = 2.88$) selected contrasting items more often than children in the active ($M = 1.50$, $SD = 2.04$) and inactive control groups ($M = 4.2$ $SD = 2.48$), $t(38) = 6.84$, $p <.001$, and $t(38) = 3.17$, $p < .01$, respectively. Likewise, children in the contrastive negation training group ($M = 4.45$, $SD = 2.96$) verbalized contrastive negation more than children in the active ($M= 0.50$, $SD = 0.95$) and inactive control groups (Verbal $M = 2.1$, $SD = 2.12$), $t(38) = 5.67$, $p < .001$, and $t(38)=2.88$, $p <.001$, respectively.

Performance on the EF Scale and the Hand Game were moderately correlated, $r(56) = .39$, $p = .003$, thus scores on these tasks were combined to yield a composite EF measure of change in EF performance from pre to post-test. This was accomplished by transforming raw scores for each task into Z scores and summing them to create EF composite scores for the pre-test and post-test, which were then used to calculate difference scores to be used in analyses. Performance on the Day/Night Stroop was not significantly correlated with either the EF Scale or the Hand Game and thus performance on this task was examined separately. Table 6 presents change in performance on the individual EF measures by condition.

To examine the primary hypothesis that children who received linguistic experience involving contrastive negation would show more increases in EF from pre- to post-test than the two control groups, a one-way ANOVA was conducted, which was significant, $F(2, 53) = 5.63$, $p = .006$. This finding was followed up with post hoc t-tests using the Bonferroni correction for multiple comparisons, and it was found that children in the contrastive negation condition performed better on the composite EF measure ($M = .74$, $SD = 1.03$) than children in the active control ($M = -.48$, $SD = 1.11$) and inactive control ($M = -.24$, $SD = 1.19$) conditions, $t(36) = 3.51$, $p = .001$, and $t(35) = 2.67$, $p = .01$. Performance in the two control conditions did not significantly differ, $t(35) = -.63$, $p = .53$. See Figure 5 for a line graph summarizing these findings.

Children who responded more to the contrastive negation training, as indexed by their tendency to select contrasting items on the FCT (greater or equal to 8 items out of 12), showed greater pre-post change on the EF composite ($n = 10$, $M = .88$, $SD = .82$) than children who responded less ($n = 9$, $M = .58$, $SD = 1.26$). This difference was not significant, however, likely in part due to the small sample size.

The pattern found in performance on the Day/Night Stroop across groups was consistent with the pattern found on the EF composite. An ANOVA was conducted with condition as the independent variable and performance on the Day/Night Stroop as the dependent variable, yielding a nonsignificant trend, $F(2, 52) = 1.74$, $p = .18$. This was followed up with exploratory post-hoc t-tests, finding that the contrastive negation condition improved more from pre- to post-test on the Day/Night Stroop ($M = 1.67$, $SD = 3.20$) than the Storybook condition ($M = -1.06$, $SD = 4.41$), $t(34) = 2.12$, $p = .041$. However, this difference may not be entirely attributable to the contrastive negation exposure, as children in the Storybook condition on average performed *worse* at post-test on the Day/Night Stroop. The same general trend was present for the contrastive negation condition versus the stimuli only condition ($M = 0.11$, $SD = 5.26$), however the difference was much smaller, $t(35) = 1.084$, $p = .286$. When the contrastive negation condition was compared to performance in the control conditions collapsed together ($n = 37$, $M = -.46$, $SD = 4.83$), the difference was trending towards significance, $t(53) = 1.69$, $p = .097$. A further, exploratory analysis found that children significantly improved from pre- to post-test (*M*s = 12.27, $SD = .91$; Post test: $M = 13.94$, $SD = .91$) on the Day/Night Stroop in the contrastive negation condition, $t(17) = 2.21$, $p = .041$, whereas there was no significant improvement on this task in either the stimuli only or storybook control conditions, *p*s > .32.

Discussion

Study 2 found that children familiarized with contrastive negation showed greater improvement in EF than children not provided with this linguistic experience. Children in the contrastive negation condition showed greater improvement than children who were exposed to the same stimuli without contrastive negation, suggesting that it is not mere exposure to contrasting stimuli that matters, but rather language that familiarizes children with talking and thinking about contrasting information. These findings support the hypothesis that experience with contrastive negation helps children represent contrasting information, such as conflicting rules, leading to conflict detection and activation of executive control. Furthermore, after exposure to contrastive negation across a variety of tasks, children in the contrastive negation condition tended to spontaneously focus on contrast, as indexed by their tendency to select contrasting pictures on the FCT and verbalize contrastive negation. This confirms that children in this condition were primed by the training to notice contrasting information, further supporting the interpretation that experience with contrastive negation provides children with a new psychological framework that they can apply to the world, allowing them to take notice of information in new ways.

Performance on the Day/Night Stroop corresponded to a similar pattern of performance on the EF composite but there was no significant condition effect. There are several reasons why this might have occurred. The most interesting possibility is that the other EF tasks use language that explicitly contrasts the old and new rules, which may have interacted with the neural representation of recently practiced contrastive negation framework. For example, on the EF scale, the post-switch instructions explicitly indicate that a new game is being played, not the old game. Likewise, the anti-imitation phase of the Hand Game is introduced with the experimenter indicating that a new, different game is being played. In the Day/Night Stroop, no such contrast is expressed between the canonical associations (day and sun, night and moon) and the rules of the current game. It is possible that if such a contrast were emphasized, then children would be better able to represent the expected way of doing things in contrast to the task instructions, which in turn would make the conflict more apparent.

On the other hand, there may have been other issues related to the measure itself that reduced its power to detect change in EF across sessions. Interestingly, the Day/Night Stroop was not correlated with the other EF tasks or with age. There are some possible reasons for this. First, the task is inherently noisier given that some children will not have developed (through their prior linguistic experience) a strong prepotent response based on the associations between day/sun and night/moon, and may thus actually perform relatively well on the task while doing poorly on the other EF measures (which would account for the lack of correlation between the Day/Night Stroop and the other EF measures). Second, children sometimes respond correctly or incorrectly in ways that are not interpretable as being clearly related to inhibitory control. About 29% of children at pre-test (n = 17) completed between 10-12 trials correctly on the Day/Night Stroop. A nontrivial subset of these children (at least 9) achieved this score by alternating between saying ‘day’ and ‘night’ or just saying ‘day’ or ‘night’ for all trials (these patterns were noted by Gerstadt et al., 1994). Because children’s responses can be influenced by what they hear themselves saying, this task appears to be more inherently noisy than EF scale and Hand Game.

General Discussion

The current research aimed to examine the role that linguistic experience might play in conflict detection and EF by testing whether experience with contrastive negation is associated with better EF in young children. Study 1 examined this via a correlational study, finding that children who spontaneously used contrastive negation tended to perform better on a widely used measure of conflict EF, controlling for age and verbal IQ. Study 2 found that children who were exposed to contrastive negation showed greater improvement on EF tasks than children who did not receive such linguistic experience. Together, these studies provide the first evidence that linguistic experience plays a role in the development of conflict detection and EF in young children. This finding calls for integration between cognitive neuroscience and developmental psychological models, insofar as it suggests that there is much to be learned about how conflict detection works by considering psychological experience and development.

Specifically, the current research provides evidence for the idea that a specific linguistic device, contrastive negation, may serve as a kind of psychological tool in the Vygotskian sense that allows one to both notice conflict and represent it via inner speech. That is, in accordance with both the LOC model and CCC-r theory (Zelazo, 1999; 2004), it is proposed that experience with contrastive negation facilitated the consideration of competing rules in contradistinction (e.g., *Not shape game; color game.),* increasing the likelihood that children would detect conflict between the rules, and also that they would be able to construct a higher-order rule to coordinate the incompatible lower-order rules to guide behavior. This serves as a developmental psychological account of the process involved in conflict detection described by conflict monitoring theory.

More generally, the current research provides new evidence that linguistic experience plays a role in the development of conscious, reflective deliberate thought and action, a hallmark of human cognition and foundational to our nature as self-aware beings. Consistent with Vygotsky's theoretical account, these studies suggest that early linguistic experience can play a fundamental role in shaping core higher-order cognitive processes like EF, by providing the tools that allow one to represent and respond to complexity in the world.

The reported studies were conducted primarily to test the hypothesis that contrastive negation aids conflict detection, however, as noted, experience with negation may also aid EF by providing the language needed to effectively integrate conflicting rules in complex rule representations via inner speech. Representations of rules involving negation (e.g., "*Don't* focus on the word," in the Stroop task) may facilitate inhibition of task irrelevant neural activity. It has long been speculated that using negation one can inhibit beliefs and corresponding actions, and that this function derives from parental prohibition using 'no' and 'don't' (Russell, 1948; Pea, 1980). Furthermore, in light of the evidence and theory suggesting that EF is mediated by inner speech, it is plausible that being able to effectively process and represent rules using negation may allow one to inhibit attention to irrelevant rules and thereby refocus attention on relevant rules guiding adaptive action. Recent research in neurolinguistics supports this idea, indicating that negation affects the accessibility concept and action representations. MacDonald and Just (1989) presented young adults with sentences in which a noun was negated (e.g., 'Sally baked cookies, *not* bread') and found that participants were slower to indicate whether the probe had appeared in the sentence if the probe corresponded to a negated noun. Researchers have also found evidence that processing action sentences involving negation reduces activation of brain areas corresponding to the action-representation system (Tetamanti et al., 2008). Participants listened to affirmative and negative action-related sentences while brain activity was recorded using fMRI, and it was found that presentation of negative action related sentences resulted in reduced activity in the action-representation system compared to affirmative sentences.

Early developmental research on the effect of negative self-commands on representation and action also suggests that negation plays a role in inhibitory control. Experiments by Luria (1961) found that children performed better on a two-light task (in which they were to press a button when presented with a red light and refrain from responding when presented with a green light) when the experimenter provided relevant verbal commands (“Press” and “Don’t press”). Findings of later experiments (Tikhomirov, 1978) in which children were instructed to accompany their actions with verbal self-commands were less clear, indicating worsened performance in young children when self-commands were spoken (versus performing the focal task silently), but improved performance in older children.

Thus it could be that negation facilitates children’s ability to switch flexibly when a subdominant response must be activated and a dominant response inhibited, by permitting the child to selectively attend to and process stimulus characteristics that are relevant to the current rules they must observe in order to act adaptively. Being able to negate in mind the irrelevant, conflicting rules (e.g., “*Not* the shape game”) may allow children to simultaneously inhibit prepotent tendencies and instead act upon relevant rules. On the current view, verbally-mediated contrastive representations likely facilitates control via both of these pathways, simultaneously making one aware of conflict and prompting control, and also serving as a tool to represent complex rules, thereby instantiating the inhibition of interfering thoughts/rules. For example, thinking, "*Reading; not searching,"* may both make a person more aware of conflict related to pursing their goal, prompting control (e.g., heightened vigilance), and may also serve as a self-direction that effectively inhibits activation of brain areas related to searching.

What does this research suggest about how EF works beyond the laboratory? The EF tasks that children completed in these studies are laboratory tasks and so it might be argued that even if contrastive negation training enhances performance on these tasks, this does not imply that such training would prove useful when children encounter real world demands. However, while the tasks used in this research do not obviously resemble the EF demands that children and adults confront in their daily lives, at their core these tasks are modeling the conflict that occurs when new goals run up against well-established habits. Young children experience great difficulty acting in light of new goals in such situations, and are easily seduced into "mindlessly" following pre-established patterns. Adults may show similar patterns in some contexts, for example, when mind-wandering (McVay & Kane, 2010) or ruminating (Watkins & Brown, 2002). The current research suggests that in such contexts, when one course of action is in conflict with another (e.g., a current goal versus other desires or tendencies), the ability to spontaneously construct verbal representations that represent this conflict may be key to engaging the control processes needed to resolve it.

Does contrastive negation facilitate proactive or reactive control? Proactive control is engaged in advance of needing it, and is involved in the active maintenance of goal relevant information in anticipation of demands on cognition, whereas reactive control is engaged in the moment, in response to detected interference (Braver, 2012; Braver, Paxton, Locke, & Barch, 2009). Each form of control is theorized to be associated with different underlying brain mechanisms activated at different time points, with the former associated with anticipatory and sustained activation of lateral PFC, while the later is associated with late, transient activation of regions associated with conflict monitoring, such as the ACC.

This dual-mechanistic division of control processes suggests that proactive control would not be facilitated by contrastive negation training, which was expected to aid detection of conflict rather than goal maintenance. However, conflict could be anticipated given certain cues provided at the outset of a task, which in turn might lead to proactive goal maintenance that reduces subsequent demands on reactive control. This is consistent with Desender et al.'s (2014) theory and evidence that the subjective awareness of conflict leads to engagement of control and not the mere presence of response conflict. In theory, awareness of conflict could occur as early as when task instructions are provided. Indeed, in the tasks used in the current research, the instructions more or less explicitly indicate the conflict inherent in the task (e.g., in the DCCS: "We're not playing the shape game anymore; we're playing the color game," and in the Hand Game: “Now we’re going to play a different game where you make a different shape than me”). In the Day/Night Stroop the conflict inherent in the task is more implicit: “When I show you a sun, you say *night*”. Thus, on the current view, experience with contrastive negation may facilitate proactive control by improving children’s ability to notice and represent the conflict inherent in a given EF task at the outset of the task.

On the other hand, experience with contrastive negation likely also facilitates reactive control. An integrated representation of conflicting task rules may help children notice interference more readily in the midst of the task and engage control on an ‘as need’ basis. This is consistent with the fact that on the Hand Game, most errors were self-corrections, indicating reactive control. Thus the key difference in the reactive versus proactive conceptual distinction is how control is engaged (e.g., by self-directed prompting at the outset of a task versus bottom-up interference during the task). In Braver’s schematic (2012), in both cases the engagement of control involves some sort of verbal self-direction concerning what to do *and* what not to do (e.g., on the Stroop task: “*Attend to color and/or ignore word*”).

The putative role of contrastive negation in proactive and reactive control can be further illustrated through the example of adults and mind-wandering. A person might have the goal of reading an intellectually challenging article online, which may in turn evoke mild negative feelings given the effort required, prompting some desire to avoid the task one has set for oneself. This may result in the rather automatic tendency to give undue attention to thoughts that arise while reading (following up on them with searches on the Internet, for example), which would effectively derail the goal of reading. In the presence of a verbally-mediated representation contrasting the goal with off-task behavior (e.g., *"Reading; not searching"),* one may be in a better position to maintain one's goal in mind while inhibiting other tendencies and proactively self-regulate. Similarly, one may more readily catch oneself veering off task and engage reactive control given the presence of a verbally-mediated representation contrasting current goals with other ongoing desires.

While the current studies were designed to test the hypothesis that language that helps one represent contrasting information improves conflict detection and EF, it is possible that the training aided performance via some other route. Given that children were exposed to a variety of tasks using contrastive negation in different ways, it is possible that some specific feature of one of the tasks was responsible for the effect than the general experience provided with contrastive negation. This points to a trade-off inherent in designing a study that aims to provide naturalistic linguistic input that is intended to facilitate a certain way of thinking that will then be generalized to a new situation. If the linguistic input provided was more restricted, it is probable that the manipulation would have been unlikely to induce a general contrastive negation framework that could be generalized to the EF context. Along the same lines, the word *different* was used extensively in the contrastive negation training condition. This may suggest that children in this condition improved more than other conditions not because of exposure to contrastive negation but rather due to training in the use of the word *different*. A more "tight" control condition might have also used the word different but not contrastive negation, or vice versa. However, the primary goal of this study was not to isolate the effect of exposure to negation per se but rather to provide linguistic experience that was expected to support children's ability to represent incompatibility and thereby detect conflict. In other words, the concept of difference was not independently trained in the study; the word was simply used to further emphasize that negated attributes, objects, or actions were distinct from affirmed ones.

Another limitation of the current research is the absence of any direct measure of conflict detection. Thus it cannot be argued conclusively that experience with contrastive negation resulted in better EF via improved conflict detection. Future research should include such measures (e.g., EEG or other indices). Nevertheless, the specific linguistic manipulation that was undertaken was chosen solely based on the expectation that such experience would enhance EF via conflict detection. The finding of improvement in EF under this manipulation thus provides indirect evidence that conflict detection can be improved given certain linguistic experience.

This research suggests new possibilities for studying the influence of linguistic experience on the development and exercise of EF. For example, experiments could be designed to examine whether experience with contrastive negation aids both conflict detection and complex rule representation, and to examine how negation might instantiate both conflict detection and response inhibition in the brain. Behavioral methods such as the tasks used in the current study could be complemented with indices of brain activity such as EEG and pupilometry, to provide more insight into the mechanisms through which such linguistic input exerts its influence. For example, EEG and pupilometry could provide more information about whether linguistic training influences proactive or reactive control (or both). Reaction time measurements may also reveal whether experience with contrastive negation facilitates conflict resolution (leading to faster reaction times). Other experimental designs could be used to address whether experience with contrastive negation facilitates higher-order representations and inhibition.

Another worthwhile goal for future research would be to replicate and extend the current findings using a wider age range. The current age group was selected because of expectations concerning linguistic experience and as well as the age appropriateness of the conflict EF tasks. Given that EF develops gradually across childhood into adolescence, one would expect that linguistic experience plays a role beyond the narrow age window of 3 to 4 years. Similarly, generalizing these findings to a wider range of EF tasks would provide more support for the idea that negation plays a critical role in the development and exercise of EF.

The current research examined the role of linguistic experience in the development of conflict detection and EF and represents a first step in the direction of fruitfully integrating theories in cognitive development and cognitive neuroscience. It is clear that each of these theoretical traditions has yielded important insights that have both constrained and expanded models of EF. Further work at the intersection of these traditions promises to be mutually revealing and to deepen our knowledge concerning the nature of EF.

References

Bechara, A., Damasio, A. R., Damasio, H., & Anderson, S. W. (2013). Insensitivity to future consequences following damage to human prefrontal. *Personality and Personality Disorders: The Science of Mental Health*, *50*, 287. doi:10.1016/0010-0277(94)90018-3

Behrend, D. A., Rosengren, K., & Perlmutter, M. (1989). A new look at children's private speech: The effects of age, task difficulty, and parent presence. *International Journal of Behavioral Development, 12,* 305-320. doi: 10.1177/016502548901200302

Biederman, J., Monuteaux, M. C., Doyle, A. E., Seidman, L. J., Wilens, T. E., Ferrero, F., & Faraone, S. V. (2004). Impact of executive function deficits and attention-deficit/hyperactivity disorder (ADHD) on academic outcomes in children. *Journal of Consulting and Clinical Psychology, 72,* 757-766. doi: 10.1037/0022-006X.72.5.757

Blair, C., & Razza, R. P. (2007). Relating effortful control, executive function, and false belief understanding to emerging math and literacy ability in kindergarten. *Child Development*, *78*, 647–663. doi: 10.1111/j.1467-8624.2007.01019.x

Bloom, L. (1970). *Language development: Form and function in emerging grammars.* Cambridge: MIT Press.

Bohlmann, N. L., & Fenson, L. (2005). The effects of feedback on perseverative errors in preschool aged children. *Journal of Cognition and Development*, *6*(1), 119-131. doi:10.1207/s15327647jcd0601_7

Botvinick, M. M., Braver, T. S., Barch, D. M., Carter, C. S., & Cohen, J. D. (2001). Conflict monitoring and cognitive control. *Psychological Review, 108*(3), 624. doi: 10.1037/0033-295X.108.3.624

Botvinick, M. M., Cohen, J. D., & Carter, C. S. (2004). Conflict monitoring and anterior cingulate cortex: an update. *Trends in Cognitive Sciences*, *8*(12), 539-546. doi: 10.1016/j.tics.2004.10.003

Braver, T. S. (2012). The variable nature of cognitive control: a dual mechanisms framework. *Trends in cognitive sciences*, *16*(2), 106-113.

Braver, T. S., Paxton, J. L., Locke, H. S., & Barch, D. M. (2009). Flexible neural mechanisms of cognitive control within human prefrontal cortex. *Proceedings of the National Academy of Sciences, 106*(18), 7351-7356.

Bunge, S. A., & Zelazo, P. D. (2006). A brain-based account of the development of rule use in childhood. *Current Directions in Psychological Science, 15,* 118-121. doi: 10.1111/j.0963-7214.2006.00419.x

Carlson, S. M., & Moses, L. J. (2001). Individual differences in inhibitory control and children's theory of mind. *Child Development*, *72*(4), 1032-1053. doi:10.1111/1467-8624.00333

Carlson, S. M. (2005). Developmentally sensitive measures of executive function in preschool children. *Developmental Neuropsychology*, *28*, 595–616. doi: 10.1207/s15326942dn2802_3

Carlson, S. M., & Beck, D. M. (2009). Symbols as tools in the development of executive function. In Winsler, A., Fernyhough, C., & Montero, I. (Eds.). (2009). *Private speech, executive functioning, and the development of verbal self-regulation* (pp. 163-175). Cambridge: Cambridge University Press.

Carlson, S. M. (2013). *EF scale for early childhood.*

Cragg, L., & Nation, K. (2010). Language and the development of cognitive control. *Topics in Cognitive Science*, *2*(4), 631-642. doi:10.1111/j.1756-8765.2009.01080.x

Cunningham, W. A., & Zelazo, P. D. (2007). Attitudes and evaluations: A social cognitive neuroscience perspective. *Trends in Cognitive Sciences*, *11*(3), 97-104. doi:10.1016/j.tics.2006.12.005

Desender, K., Van Opstal, F., & Van den Bussche, E. (2014). Feeling the conflict: The crucial role of conflict experience in adaptation. *Psychological Science*, 25, 675-683. doi: 10.1177/0956797613511468

de Villiers, J. G., & de Villiers, P. A. (2000). Linguistic determinism and the understanding of false beliefs. In P. Mitchell and K. J. Riggs (Eds), *Children's reasoning and the mind* (pp. 191-228). Hove, England: Psychology Press.

De Villiers, J. G., & Pyers, J. E. (2002). Complements to cognition: A longitudinal study of the relationship between complex syntax and false-belief-understanding. *Cognitive Development, 17*(1), 1037-1060. doi: 10.1016/S0885-2014(02)00073-4

Diamond, A. (2002). Normal development of prefrontal cortex from birth to young adulthood: Cognitive functions, anatomy, and biochemistry. In Stuss, Donald T. (Ed); Knight, Robert T. (Ed), (2002). *Principles of frontal lobe function.* (pp. 466-503). New York, NY, US: Oxford University Press. doi: 10.1093/acprof:oso/9780195134971.003.0029

Diamond, A. (2012). Activities and programs that improve children's executive functions. *Current Directions in Psychological Science, 21,* 335-341. doi: 10.1177/0963721412453722

Diamond, A. (2013). Executive functions. *Annual Review of Psychology*, *64*, 135-168. doi:10.1146/annurev-psych-113011-143750

Doebel, S. & Zelazo, P. D. A meta-analysis of task factors influencing performance on the dimensional change card sort: Implications for the measurement and training of executive function. Manuscript under review.

Emerson, M. J., & Miyake, A. (2003). The role of inner speech in task switching: A dual-task investigation. *Journal of Memory and Language, 48,* 148-168. doi: 10.1016/S0749-596X(02)00511-9

Espinet, S. D., Anderson, J. E., & Zelazo, P. D. (2011). N2 amplitude as a neural marker of executive function in young children: An ERP study of children who switch versus perseverate on the Dimensional Change Card Sort. *Developmental Cognitive Neuroscience, 2,* S49-S58. doi: 10.1016/j.dcn.2011.12.002

Espinet, S. D., Anderson, J. E., & Zelazo, P. D. (2013). Reflection training improves executive function in preschool-age children: Behavioral and neural effects. *Developmental Cognitive Neuroscience, 4,* 3-10. doi:10.1016/j.dcn.2012.11.009

Eshel, N., Nelson, E. E., Blair, R. J., Pine, D. S., & Ernst, M. (2007). Neural substrates of choice selection in adults and adolescents: development of the ventrolateral prefrontal and anterior cingulate cortices. *Neuropsychologia*, *45*(6), 1270-1279. 10.1016/j.neuropsychologia.2006.10.004

Fernyhough, C., & Fradley, E. (2005). Private speech on an executive task: Relations with task difficulty and task performance. *Cognitive Development, 20,* 103-120. doi: 10.1016/j.cogdev.2004.11.002

Flavell, J. H., Beach, D. R., & Chinsky, J. M. (1966). Spontaneous verbal rehearsal in a memory task as a function of age. *Child Development, 37,* 283-299. doi: 10.2307/1126804

Frye, D., Zelazo, P. D., & Palfai, T. (1995). Theory of mind and rule-based reasoning. *Cognitive Development*, *10*, 483–527. doi: 10.1016/0885-2014(95)90024-1s

Gathercole, S. (1998). The development of memory. *Journal of Child Psychology and Psychiatry, 39,* 3-27. doi: 10.1111/1469-7610.00301

Gratton, G., Coles, M. G., & Donchin, E. (1992). Optimizing the use of information: strategic control of activation of responses. *Journal of Experimental Psychology: General*, *121*(4), 480. doi:10.1037/0096-3445.121.4.480

Gerstadt, C. L., Hong, Y. J., & Diamond, A. (1994). The relationship between cognition and action: performance of children 312–7 years old on a stroop-like day-night test. *Cognition*, *53*(2), 129-153. doi: 10.1016/0010-0277(94)90068-X

Gogtay, N., Giedd, J. N., Lusk, L., Hayashi, K. M., Greenstein, D., Vaituzis, A. C., ... & Thompson, P. M. (2004). Dynamic mapping of human cortical development during childhood through early adulthood. *Proceedings of the National Academy of Sciences of the United States of America*, *101*(21), 8174-8179. doi:10.1073/pnas.0402680101

Jacques, S., & Zelazo, P. D. (2005). Language and the development of cognitive flexibility: Implications for theory of mind. In J. W. Astington, & J. A. Baird (Eds.), *Why language matters for theory of mind* (pp. 144-162). New York: Oxford University Press.

Jarrold, C., Cowan, N., Hewes, A. K., & Riby, D. M. (2004). Speech timing and verbal short-term memory: Evidence for contrasting deficits in Down syndrome and Williams syndrome. *Journal of Memory and Language, 51,* 365-380. doi: 10.1016/j.jml.2004.06.007

Hammond, S. I., Müller, U., Carpendale, J. I., Bibok, M. B., & Liebermann-Finestone, D. P. (2012). The effects of parental scaffolding on preschoolers' executive function. *Developmental Psychology*, *48*, 271. doi:10.1037/a0025519

Hongwanishkul, D., Happaney, K. R., Lee, W. S., & Zelazo, P. D. (2005). Assessment of hot and cool executive function in young children: Age-related changes and individual differences. *Developmental Neuropsychology*, *28*(2), 617-644. doi: 10.1207/s15326942dn2802_4

Hostinar, C. E., Stellern, S. A., Schaefer, C., Carlson, S. M., & Gunnar, M. R. (2012). Associations between early life adversity and executive function in children adopted internationally from orphanages. *Proceedings of the National Academy of Sciences*, *109,* 17208-17212. doi: 10.1073/pnas.1121246109

Hughes, C. (1998). Executive function in preschoolers: Links with theory of mind and verbal ability. *British Journal of Developmental Psychology*, *16*, 233-253. doi:10.1111/j.2044-835X.1998.tb00921.x

Hughes, C. (1998). Finding your marbles: Does preschoolers' strategic behavior predict later understanding of mind? *Developmental Psychology, 34,* 1326–1339. doi: 10.1037/0012-1649.34.6.1326

Hughes, C. H., & Ensor, R. A. (2009). How do families help or hinder the emergence of early executive function? *New Directions for Child and Adolescent Development*, *123,* 35-50. doi: 10.1002/cd.234

Kahneman, D. (2011). *Thinking, fast and slow*. Macmillan.

Kelly, A. C., Di Martino, A., Uddin, L. Q., Shehzad, Z., Gee, D. G., Reiss, P. T., ... & Milham, M. P. (2009). Development of anterior cingulate functional connectivity from late childhood to early adulthood. *Cerebral Cortex*, *19*(3), 640-657. doi: 10.1093/cercor/bhn117

Kloo, D., & Perner, J. (2005). Disentangling dimensions in the Dimensional Change Card-Sorting Task. *Developmental Science*, *8*(1), 44-56. doi:10.1111/j.1467-7687.2005.00392.x

Kray, J., Eber, J., & Karbach, J. (2008). Verbal self-instructions in task switching: a compensatory tool for action control deficits in childhood and old age? *Developmental Science, 11*(2), 223-236. doi: 10.1111/j.1467-7687.2008.00673.x

Landry, S. H., Miller-Loncar, C. L., Smith, K. E., & Swank, P. R. (2002). The role of early parenting in children's development of executive processes. *Developmental Neuropsychology*, *21*, 15-41. doi:10.1207/S15326942DN2101_2

Lohmann, H., & Tomasello, M. (2003). The role of language in the development of false belief understanding: A training study. *Child Development, 74*(4), 1130-1144. doi: 10.1111/1467-8624.00597

Luria, A. R. (1959). The directive function of speech in development and dissolution. *Word*, *15*, 341-352.

Luria, A. R. (1961). *The role of speech in the regulation of normal and abnormal behavior.* London: Pergamon Press Ltd.

Luria, A. R., Pribram, K. H., & Homskaya, E. D. (1964). An experimental analysis of the behavioral disturbance produced by a left frontal arachnoidal endothelioma (meningioma). *Neuropsychologia, 2,* 257–280.

MacDonald, M.C., & Just, M.A. (1989). Changes in activation levels with negation. *Journal of Experimental Psychology, 15,* 633-642. doi:10.1037/0278-7393.15.4.633

Mazzocco, M. M., & Kover, S. T. (2007). A longitudinal assessment of executive function skills and their association with math performance. *Child Neuropsychology*, *13*, 18-45. doi: 10.1080/09297040600611346

McVay, J. C., & Kane, M. J. (2010). Does mind wandering reflect executive function or executive failure? Comment on Smallwood and Schooler (2006) and Watkins (2008). *Psychological Bulletin, 136*(2), 188-197. doi: 10.1037/a0018298

Miyake, A., Friedman, N. P., Emerson, M. J., Witzki, A. H., Howerter, A., & Wager, T.

D. (2000). The unity and diversity of executive functions and their contributions to complex “frontal lobe” tasks: A latent variable analysis. *Cognitive Psychology*, *41*, 49-100. doi: 10.1006/cogp.1999.0734

Moffitt, T. E., Arseneault, L., Belsky, D., Dickson, N., Hancox, R. J., Harrington, H. L., Houts, R., et al. (2011). A gradient of childhood self-control predicts health, wealth, and public safety. *Proceedings of the National Academy of Sciences*, *108*, 2693-2698. doi: 10.1073/pnas.1010076108

Munakata, Y., & Yerys, B. E. (2001). All together now: When dissociations between knowledge and action disappear. *Psychological Science*, *12*(4), 335-337. doi: 10.1111/1467-9280.00361

Nelson, C. A. (1999). Neural plasticity and human development. *Current Directions in Psychological Science*, *8*(2), 42-45. doi:10.1111/1467-8721.00010

Pea, R. D. (1980). The development of negation in early child language. In D. R. Olson (Ed.), *The social foundations of language and thought: Essays in honor of Jerome S. Bruner* (pp. 156-86). New York: W.W. Norton.

Pennington, B. F., & Ozonoff, S. (1996). Executive functions and developmental psychopathology. *Journal of Child Psychology and Psychiatry*, *37*(1), 51-87. doi:10.1111/j.1469-7610.1996.tb01380.x

Russell, B. (1948). Human knowledge: Its scope and limits. Oxford, England: Simon & Schuster.

Talwar, V., Carlson, S. M., & Lee, K. (2011). Effects of a punitive environment on children's executive functioning: A natural experiment. *Social Development*,*20*(4), 805-824. doi:10.1111/j.1467-9507.2011.00617.x

Tam, H., Jarrold, C., Baddeley, A. D., & Sabatos-DeVito, M. (2010). The development of memory maintenance: Children’s use of phonological rehearsal and attentional refreshment in working memory tasks. *Journal of Experimental Child Psychology, 107,* 306-324. doi: 10.1016/j.jecp.2010.05.006

Tettamanti, M., Manenti, R., Della Rosa, P. A., Falini, A., Perani, D., Cappa, S. F., & Moro, A. (2008). Negation in the brain: Modulating action representations. *Neuroimage*, *43*, 358-367. doi:10.1016/j.neuroimage.2008.08.004

Vygotsky, L. S. (1962). *Thought and language* (E. Hanfmann & G. Vakar, Trans.). Cambridge, MA: MIT Press.

Watkins, E., & Brown, R. G. (2002). Rumination and executive function in depression: An experimental study. *Journal of Neurology, Neurosurgery & Psychiatry, 72*(3), 400-402.

Winsler, A., Fernyhough, C., & Montero, I. (Eds.). (2009). *Private speech, executive functioning, and the development of verbal self-regulation*. New York: Cambridge University Press.

Zaitchik, D., Iqbal, Y., & Carey, S. (2014). The effect of executive function on biological reasoning in young children: an individual differences study. *Child Development*, *85*(1), 160-175. doi:10.1111/cdev.12145

Zelazo, P. D. (2004). The development of conscious control in childhood. *Trends in Cognitive Sciences, 8,* 12–17. doi: 10.1016/j.tics.2003.11.001

Zelazo, P. D. (1999). Language, levels of consciousness, and the development of intentional action. In P. D. Zelazo, J. W. Astington, & D. R. Olson (Eds.), *Developing theories of intention: Social understanding and self-control* (pp. 95-117). Mahwah, NJ, US: Lawrence Erlbaum Associates Publishers.

Zelazo, P. D., Anderson, J. E., Richler, J., Wallner-Allen, K., Beaumont, J. L., & Weintraub, S. (2013). NIH Toolbox Cognition Battery (NIHTB-CB): Measuring executive function and attention. In P. D. Zelazo & P. J. Bauer (Eds.), National Institutes of Health Toolbox Cognition Battery (NIHTB-CB): Validation for children between 3 and 15 years. *Monographs of the Society for Research in Child Development, 78 (4),* 1-172.

Zelazo, P. D., Frye, D., & Rapus, T. (1996). An age-related dissociation between knowing rules and using them. *Cognitive Development*, *11*, 37–63. doi:10.1016/S0885-2014(96)90027-1

Zelazo, P. D., Müller, U., Frye, D., & Marcovitch, S. (2003). The development of executive function in early childhood. *Monographs of the Society for Research in Child Development*, *68*, vii-137. doi:10.1111/j.1540-5834.2003.06803001.x

Zelazo, P. D. (2006). The Dimensional Change Card Sort (DCCS): A method of assessing executive function in children. *Nature Protocols*, *1*(1), 297-301. doi:10.1038/nprot.2006.46

Appendix 1: Tables

Table 1

Focus on Contrast Task Items Used in Study 1

Target Picture	Experimenter's Statement	Similar Picture	Contrasting Picture	Irrelevant Picture
Bear in a box (center)	*There is a bear in the box.*	Bear in a box (right side)	Empty box	Window
Girl in blue walking	*The girl is walking.*	Girl in pink walking	Girl in orange sitting	Sock
Tree with ball on right side	*There is a ball near a tree.*	Tree with ball on left side	Tree with box on right side	Chair
A blooming flower.	*There is a pretty flower.*	A different blooming flower	A dying flower	Tree
Sad girl	*The girl is sad.*	Another sad girl	A girl with a neutral expression.	Moon
Jar full of cookies	*There are cookies in the jar.*	A jar with some cookies	An empty jar	Boot
Sunny sky with flowers	*It is a sunny day.*	Sunny sky with grass	Cloudy sky	Tree
Toy on a shelf	*There is a toy on the shelf.*	A different toy on a shelf	An empty shelf	Table
Spilled carton of milk (facing right)	*The milk is spilled.*	Spilled carton of milk (facing left)	Upright/closed carton of milk	Notebook
Crayons in a box	*There are crayons in the box.*	Different crayons in a box	Empty crayon box	Pencil

Table 2

Correlations Among Age and Measures in Study 1

	1	2	3	4	5	6
1. Age	–	–	–	–	–	–
2. PPVT	.13	–	–	–	–	–
3. FCT - Selection	.21	.24	–	–	–	–
4. FCT - Verbal	.28	.10	.63**	–	–	–
5. EF Scale	.14	.34*	.28*	.41**	–	–
6. Day/Night Stroop	-.14	-.03	-.03	-.13	-.01	–
7. Hand Game	.35*	.31†	.18	.11	.30†	.08

**p* < .05; ***p* < .01; †*p*<.06

Note. FCT = Focus on Contrast Task.

Table 3

Focus on Contrast Task Items Used in Study 2

Target Picture	Experimenter's Statement	Similar Picture	Contrasting Picture	Irrelevant Picture
Girl in blue walking	*The girl is walking.*	Girl in pink walking	Girl in orange sitting	Sock
Duck in a pond	*There is a duck is in the pond.*	Duck in different area of pond	Empty pond	Flower
Child playing (with toys)	*The child is playing.*	Child playing (kicking a ball)	Child sleeping	Cup
Shiny blue ring	*The ring is shiny.*	Shiny pink ring	Dull orange ring	Tree
Bear in a box (center)	*There is a bear in the box.*	Bear in a box (right side)	Empty box	Window
Spilled carton of milk (facing right)	*The milk is spilled.*	Spilled carton of milk (facing left)	Upright/closed carton of milk	Notebook
Orange tent on a hill	*There is a tent on a hill.*	Blue tent on a hill	Hill	Mushroom
Assorted flowers in a vase	*There are flowers in a vase.*	Roses in a vase	Empty vase	Fence
Sunny sky with flowers	*It is a sunny day.*	Sunny sky with grass	Cloudy sky	Tree
Table and chair on right	*There is a chair beside a table.*	Table and chair on left	Table only	Lamp
Tree with ball on right side	*There is a ball near a tree.*	Tree with ball on left side	Tree with box on right side	Chair
Girl in purple dress standing	*The girl is standing still.*	Girl in orange shirt and hat standing	Girl in red dancing	Orange ball

Table 4

Correlations Among Measures in Study 2

	1	2	3	4	5	6	7
1. Age	–	–	–	–	–	–	–
2. PPVT	.23†	–	–	–	–	–	–
3. EF Scale – pre-test	.02	.40**	–	–	–	–	–
4. Day/Night – pre-test	-.01	.13	.24†	–	–	–	–
5. Hand Game – pre-test	.06	.22†	.39**	.03	–	–	–
6. EF Scale – post-test	.23	.39**	.75**	.08	.40**	–	–
7. Day/Night – post-test	-.10	.21	.23†	.53**	.04	.09	–
8. Hand Game – post-test	-.03	.24†	.30*	.01	.59**	.37**	.19

*p < .05; **p < .01; $^{\dagger}p$<.10

Table 5

Mean Scores on Study Measures by Condition

	Contrast Training		Stimuli Only		Storybook	
Variable	*M*	*SD*	*M*	*SD*	*M*	*SD*
PPVT	85.35	16.39	80.80	15.15	88.65	17.06
FCT – selection	6.90	2.88	1.50	2.04	4.20	2.48
FCT - verbalization	4.45	2.96	0.50	0.95	2.10	2.12
EF Scale – pre-test	3.21	1.51	3.42	1.30	2.85	1.34
EF Scale – post-test	4.21	.98	3.89	1.19	3.30	1.45
Day/Night pre-test	12.42	3.82	13.42	5.22	12.21	5.01
Day/Night post-test	13.95	3.76	13.52	4.85	11.50	4.51
Hand Game – pre-test	6.95	3.57	8.10	2.85	6.89	3.48
Hand Game – post-test	9.80	2.87	8.25	2.83	8.22	2.90

Note. FCT = Focus on Contrast Task. PPVT = Peabody Picture Vocabulary Test. Task score ranges: FCT selection and verbalization: 0-12; EF Scale = 0-8; Day/Night Stroop = 0-20; Hand Game = 0-15.

Table 6

Change in Performance on EF Measures by Condition

	Contrast Training		Stimuli Only		Storybook	
Variable	*M*	*SD*	*M*	*SD*	*M*	*SD*
EF Scale	1.0	1.11	0.47	0.77	0.45	0.89
Day/Night Stroop	1.67	3.20	0.11	5.26	-1.06	4.41
Hand Game	2.85	2.08	.15	3.22	1.33	2.54

Note. EF task score ranges: EF Scale = 0-8; Day/Night Stroop = 0-20; Hand Game = 0-15.

Appendix 2: Figures

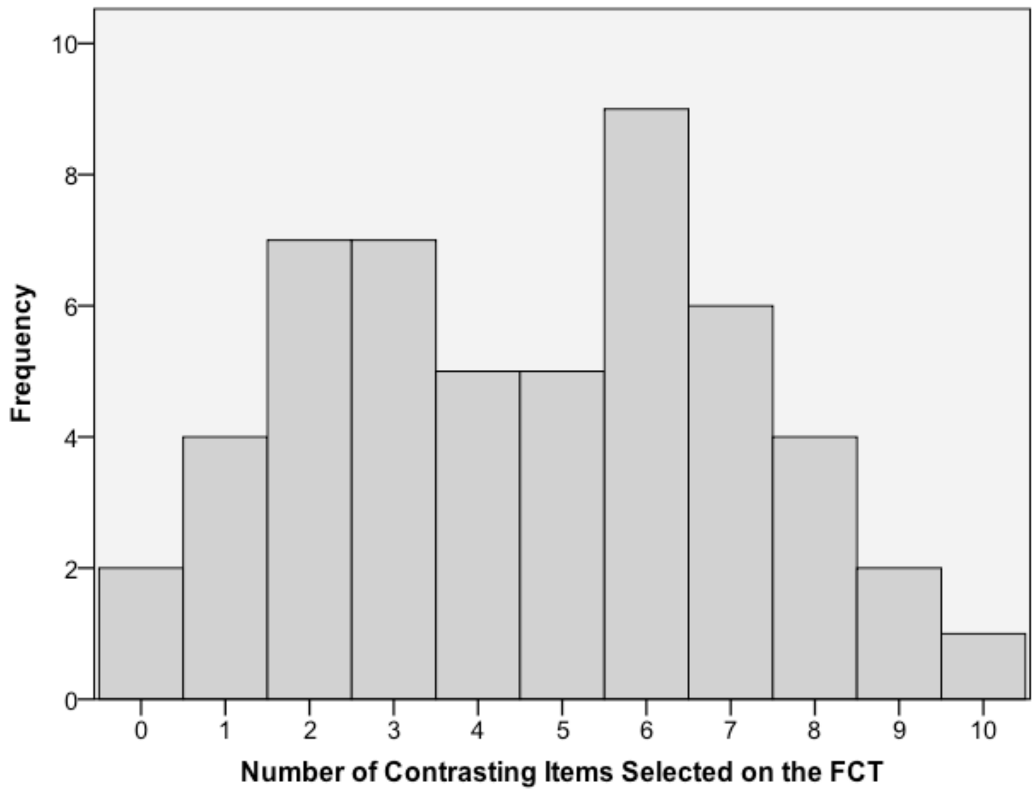

Figure 1. Histogram illustrating children's performance on the FCT, showing variance in number of contrasting items selected.

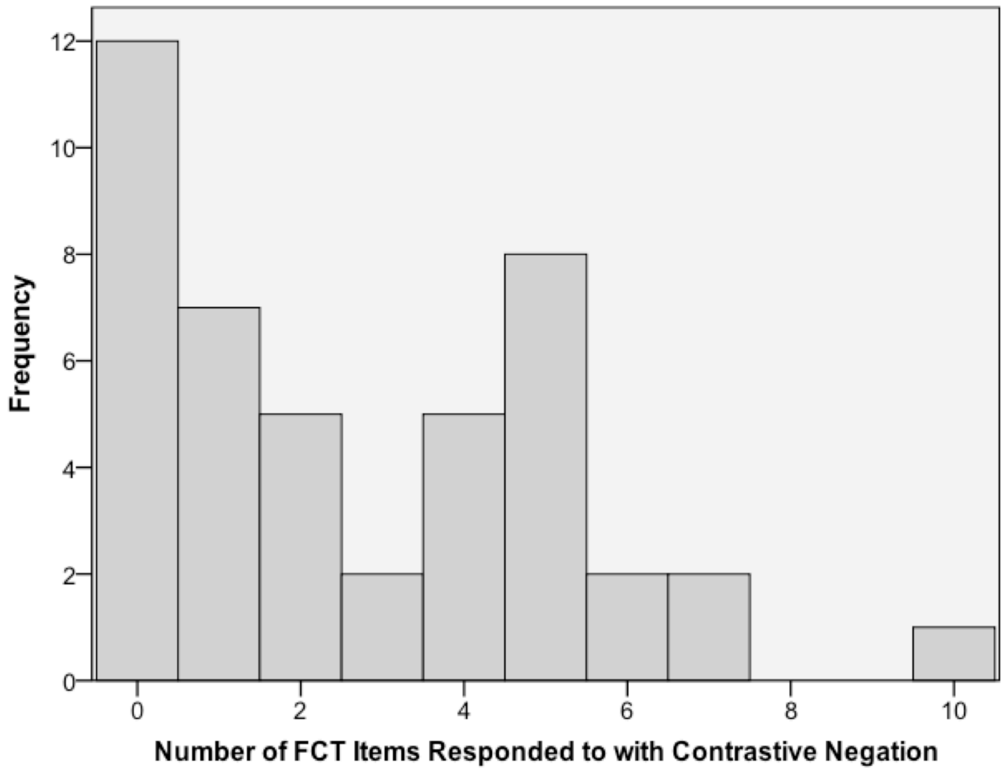

Figure 2. Histogram illustrating children's performance on the FCT, showing variance in number of children who tended to verbalize contrastive negation to justify responses to items.

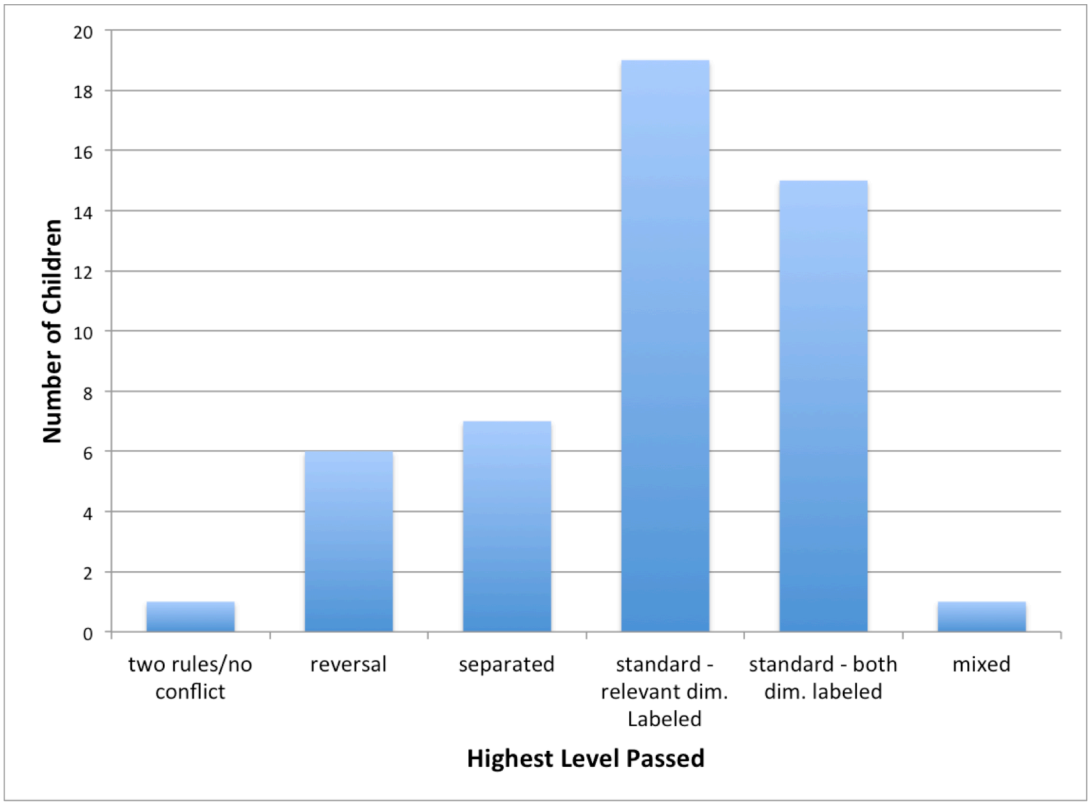

Figure 3. Three-year-olds' performance on the EF Scale in Study 1. Only 1 child passed the mixed card sort, whereas 15 failed that level and passed the standard version with both dimensions labeled.

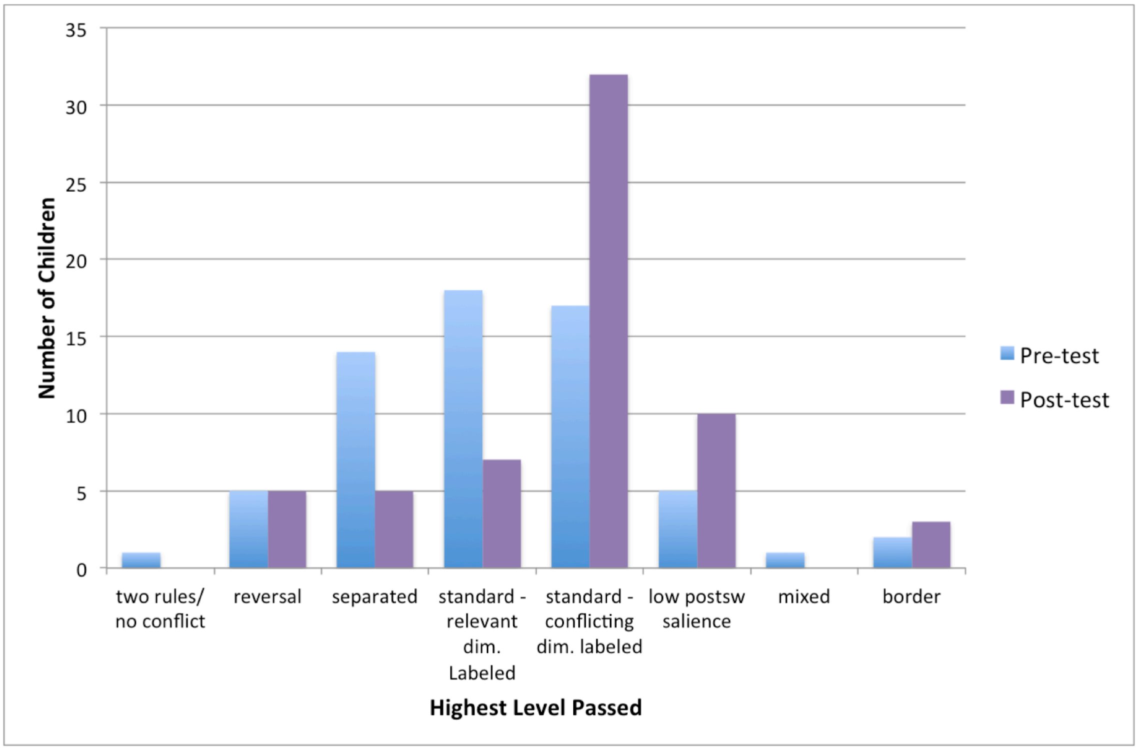

Figure 4. Three-year-olds' performance on the EF Scale at pre- and post-test in Study 2.

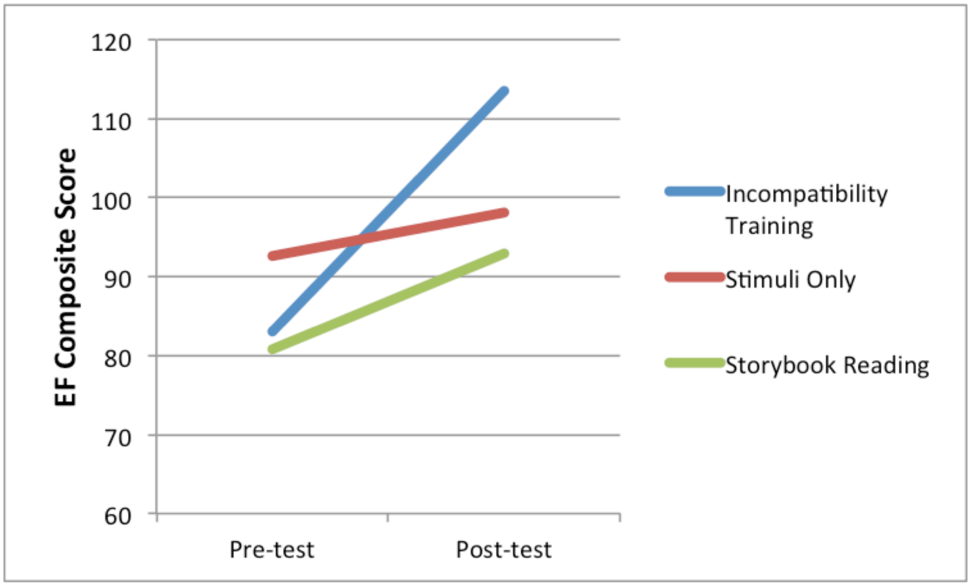

Figure 5. Change in Performance on EF composite measure by condition.

Appendix 3: Description of Levels of Modified EF Scale

Level 1: Two Rule/No Conflict Card Sort

In the pre-switch phase, children are instructed to sort cards that depict a colored shape (e.g., an orange fish) into a box that is marked by a matching target (e.g., orange fish). This box is presented along side another box is marked by a target that does not match on either dimension (e.g., grey elephant). After completing a rule check, children proceed with the 5 pre-switch trials. In the post-switch phase, children are instructed to sort new cards (e.g., grey elephant) into the other box. Children are reminded of the rules on each trial and are scored as passing this task if the successfully sort at least 4 out of 5 cards in each phase.

Level 2: Reversal Card Sort

In this task children must sort bidimensional stimuli (e.g., big dog and little dog) into two boxes with target cards that match on both dimensions. In the post-switch phase, children are instructed to play a "silly game" in which the cards are now sorted in the opposite boxes (big dogs in the little dog box, and little dogs with big dog box). As above, children complete a rule check in the pre-switch phase, are reminded of the rules on each trial, and are scored as passing this task if the successfully sort at least 4 out of 5 cards in each phase.

Level 3: Separated Card Sort

In this task children sort bidimensional stimuli into boxes that match on only one of two dimensions, such as shape (e.g., black heart with a pink background goes in the box with a black heart and a yellow background, and black flowers with a yellow background go in the box with a black flower with a pink background). Colors and shapes are spatially separated on the test and target cards. In the post-switch phase, children are instructed to sort the remaining cards by the other dimension (e.g., color), which necessitates sorting in the opposite way (e.g., black heart with a pink background now goes in the box with a black flower and a pink background). Rule reminders, rule checks, and scoring are the same as on the previous levels.

Level 4: Standard Card Sort with Relevant Dimension Labeled

This card sort is identical to the above except that the dimensional values on the test and target cards are integrated (e.g., children may sort red stars and blue trucks into boxes depicting blue stars and red trucks).

Level 5 – Study 1: Standard Card Sort with Both Dimensions Labeled

This card sort is identical to level 4 except that when the experimenter presents the test card, instead of labeling only the relevant sorting dimension (e.g., "Here is a rabbit" in the shape game), both dimensions are labeled (e.g., "Here is a red rabbit.")

Level 5 – Study 2: Standard Card Sort with Conflicting Dimension Labeled in Post-Switch Phase

This card sort is identical to level 5 in Study 1 except that during the pre-switch phase the test cards are labeled by the relevant dimension (e.g., "Here is a rabbit" in the shape game) and in the post-switch phase they are labeled by the conflicting dimension e.g., "Here is a rabbit," in the color game).

Level 6: Mixed Card Sort

This card sort departs from the bi-phasal structure inherent in the 5 previous levels and requires children to rapidly switch, in pseudorandom order, between two sorting dimensions (e.g., color and shape). The experimenter presents the test card and cues the child to "play the shape game" or "play the color game" No rule reminders are provided and children are scored as passing if they correctly sort 4 out of 5 cards in each game.

Level 7: Border Card Sort

In this card sort children are presented with test cards similar to those in levels 4-6, except that a subset of them have a black border. Children are instructed to sort by color if the card has a border and sort by shape if it does not. Two demonstration trials are followed by 12 test trials (6 border, 6 non-border presented in pseudorandom order).

Level 8: Reverse Border Card Sort

In this final level, children are instructed to sort the same cards as in level 7 but using the reverse contingency: if the test card has a black border on it, they are to play the shape game, and if the card has no border, they are to play the color game.

Appendix 4: Scripts for EF Scale (Adapted from Carlson, 2013)

1. Two Rules/No Conflict Card Sort

Introduction of stimuli:

Look, I have these boxes here. (E sets up boxes: fish box on E's left and elephant box on E's right.) This box has a fish on it (point to top of box) and this box has an elephant on it (point to top of box). Now, look who I have here! I have a fish! (show fish example card above boxes in center)

Demonstration Trial:

This is the fish game. In the fish game, all the fish go in the fish box because that's where they belong! See, here's a fish (hold up card in center). It goes here (put it in).
Now it's going to be your turn to play the fish game!

Rule Check:

Can you show me where the fish go in the fish game?

If Correct:

Very good, that's right. If Incorrect: Uh oh. Remember, in the fish game, if it's a fish, put it here (point to appropriate box). (Repeat question. If again incorrect, give reminder 1 more time only, then mark as incorrect and continue.)
Okay, let's play! Here is a fish; can you put it where it goes?

Post-switch script:

Now we're going to play a different game. We're not going to play the fish game anymore (shake head no). We're going to play the elephant game. In the elephant game, all the elephants go in the elephant box (pointing) because that's where they belong!
Okay, let's play! Here is an elephant; can you put it where it goes?

<u>2. Reversal Card Sort (Dog game to Silly Game)</u>

Now let's play a (new) game with cards!

Introduction of Stimuli:

I have these boxes here. (E sets up boxes; Big Dog on E's left, Little Dog on E's right)

This one has a big dog on it (point to top of box) and this one has a little dog on it (point). Now, look who I have here! I have a big dog, and a little dog. (Show big dog and little dog example cards one at a time above boxes in center and then return them to the stack in examiner's hand so they are not showing.)

Demonstration Trials:

This is the dog game. In the dog game, all the big dogs go in the big dog box (pointing) and all the little dogs go in the little dog box (pointing). See, here's a big dog (hold up in center). It goes in the big dog box. (put it in) And here's a little dog (hold up in center). It goes little dog box. (put it in) Now it's going to be your turn to play the dog game!

Rule Check:

Can you show me where the big dogs go in the dog game?
If Correct:

Very good, that's right.

If Incorrect:

Uh oh. Remember, in the dog game, if it's a big dog, then put it here, but if it's a little dog, put it here (pointing to appropriate boxes.) (Repeat question. If again incorrect, give reminder 1 more time only, then mark as incorrect and continue.)

Can you show me where the little dogs go in the dog game?

If Correct:

Very good, that's right.

If Incorrect:

Uh oh. Remember, in the dog game, if it's a big dog, then it goes here, but if it's a little dog, then it goes here (pointing to appropriate boxes.) (Repeat question. If again incorrect, give reminder 1 more time only, then mark as incorrect and continue.)

Okay, let's play! Here is a *big* dog; can you put it where it goes? [Rule reminder after every trial.] Here is a *little* dog…

Post-Switch Instructions:

Now we're going to play a different game. We're not going to play the old dog game anymore (shake head no). We're going to play the silly dog game. In the silly game, all

the little dogs go in the big dog box (point, slowly) and all the big dogs go in the little dog box (point, slowly). This is a silly game.
Continue to emphasize “big” and “little.”
(No demonstration trials or rule check)

Okay, let’s play! Here is a *big* dog; can you put it where it goes? (Rule reminder after every trial.) Here is a *little* dog…

3. Separated Dimensions Card Sort

Okay, let’s play a (new) game with cards!

Introduction of Stimuli:

I have these boxes here. (Box on E’s left has a red card with a black frog on it. Box on E’s right has a blue card with a black butterfly on it.)

This one has a frog on it (point to top of box) and this one has a butterfly on it (point).

Now, look what I have here! I have frogs and butterflies. (Show frog and butterfly example cards one at a time above boxes in center and then return them to the stack in examiner’s hand so they are not showing.)

Demonstration Trials:

This is the shape game. In the shape game, all the frogs go here (pointing) and all the butterflies go here (pointing).

See, here’s a frog (hold up in center). It goes in the frog box (put it in). And here’s a butterfly (hold up in center). It goes in the butterfly box (put it in). Now it’s going to be your turn to play the shape game!

Rule Check:

Can you show me where the frogs go in the shape game?

If Correct:

Very good, that’s right.

If Incorrect:

Uh oh. Remember, in the shape game, if it's a frog, then put it here, but if it's a butterfly, put it here (pointing to appropriate boxes). (Repeat question. If again incorrect, give reminder 1 more time only, then mark as incorrect and continue.)

Can you show me where the butterflies go in the shape game?

If Correct:

Very good, that's right.

If Incorrect:

Uh oh. Remember, in the shape game, if it's a frog, then put it here, but if it's a butterfly, put it here (pointing to appropriate boxes). (Repeat question. If again incorrect, give reminder 1 more time only, then mark as incorrect and continue.)

Okay, let's play! Here is a frog; can you put it where it goes? (Rule reminder after every trial.) Here is a butterfly…

Post-Switch Instructions:

Now we're going to play a different game. We're not going to play the shape game anymore (shake head no). We're going to play the color game. In the color game, all the red ones go here (pointing), and all the blue ones go here (pointing).

(No demonstration trials or rule checks.)

Okay, let's play! Here is a red one; can you put it where it goes? Here is a blue one…

4. Standard Card Sort with Relevant Dimension Labeled

Okay, let's play a (new) game with cards!

Introduction of Stimuli:

I have these boxes here. (Box on E's left has a yellow horse with a white background. Box on E's right has a pink plane with a white background.) This one is yellow (point to top of box) and this one is pink (point). Now, look what I have here! I have yellow cards and pink cards. (show yellow and pink example cards one at a time above boxes in center and then return them to the stack in examiner's hand so they are not showing)

Demonstration Trials:

This is the color game. In the color game, all the yellow ones go here (pointing) and all the pink ones go here (pointing). See, here's a yellow one (hold up in center). It goes in the yellow box (put it in). And here's a pink one (hold up in center). It goes in the pink box (put it in). Now it's going to be your turn to play the color game!

Rule Check:

Can you show me where the yellow ones go in the color game?

If Correct:

Very good, that's right.

If Incorrect:

Uh oh. Remember, in the color game, if it's yellow, then put it here, but if it's pink, put it here (pointing to appropriate boxes). (Repeat question. If again incorrect, give reminder 1 more time only, then mark as incorrect and continue.)

Can you show me where the pink ones go in the color game?

If Correct:

Very good, that's right.

If Incorrect:

Uh oh. Remember, in the color game, if it's yellow, then put it here, but if it's pink, put it here (pointing to appropriate boxes). (Repeat question. If again incorrect, give reminder 1 more time only, then mark as incorrect and continue.)

Okay, let's play! Here is a yellow one; can you put it where it goes? (Rule reminder after every trial.) Here is a pink one…

Post-Switch Instructions:

Now we're going to play a different game. We're not going to play the color game anymore (shake head no). We're going to play the shape game. In the shape game, all the horses go here (pointing) and all the planes go here (pointing).

(No demonstration trials or rule check.)

Okay, let's play! Here is a horse; can you put it where it goes? Here is a plane…

5. Standard Card Sort with - Conflicting Dimension Labeled in Post-Switch Phase

Okay, let's play a (new) game with cards!

Introduction of Stimuli:

I have these boxes here. (Box on E's left has a purple pig with a white background. Box on E's right has a green rabbit with a white background.) This one is purple (point to top of box) and this one is green (point). Now, look what I have here! I have purple cards and green cards. (show purple and green example cards one at a time above boxes in center and then return them to the stack in examiner's hand so they are not showing)

Demonstration Trials:

This is the color game. In the color game, all the purple ones go here (pointing) and all the green ones go here (pointing). See, here's a purple one (hold up in center). It goes in the purple box (put it in). And here's a green one (hold up in center). It goes in the green box (put it in). Now it's going to be your turn to play the color game!

Rule Check:

Can you show me where the purple ones go in the color game?

If Correct:

Very good, that's right.

If Incorrect:

Uh oh. Remember, in the color game, if it's purple, then put it here, but if it's green, put it here (pointing to appropriate boxes). (Repeat question. If again incorrect, give reminder 1 more time only, then mark as incorrect and continue.)

Can you show me where the green ones go in the color game?

If Correct:

Very good, that's right.

If Incorrect:

Uh oh. Remember, in the color game, if it's purple, then put it here, but if it's green, put it here (pointing to appropriate boxes). (Repeat question. If again incorrect, give reminder 1 more time only, then mark as incorrect and continue.)

Okay, let's play! Here is a green one can you put it where it goes? Here is a purple one…

Post-Switch Instructions:

Now we're going to play a different game. We're not going to play the color game anymore (shake head no). We're going to play the shape game. In the shape game, all the pigs go here (pointing) and all the rabbits go here (pointing).

(No demonstration trials or rule check.)

Okay, let's play! Here is a green one can you put it where it goes? (Rule reminder after every trial.) Here is a purple one…

6. Low Post-Switch Salience

Introduction of Stimuli:

I have these boxes here. (Box on E's left has a house with a white background. Box on E's right has a bear with a white background.) This one is a house (point to top of box) and this one is a bear (point). Now, look what I have here! I have card with houses on them and cards with bears on them. (show house and bear example cards one at a time above boxes in center and then return them to the stack in examiner's hand so they are not showing)

Demonstration Trials:

This is the shape game. In the shape game, all the houses go here (pointing) and all the bears go here (pointing). See, here's a house (hold up in center). It goes in the house box (put it in). And here's a bear (hold up in center). It goes in the bear box (put it in). Now it's going to be your turn to play the shape game!

Rule Check:

Can you show me where the house goes in the shape game?

If Correct:

Very good, that's right.

If Incorrect:

Uh oh. Remember, in the shape game, if it's a house, then put it here, but if it's a bear, put it here (pointing to appropriate boxes). (Repeat question. If again incorrect, give reminder 1 more time only, then mark as incorrect and continue.)

Can you show me where the bear goes in the shape game?

If Correct:

Very good, that's right.

If Incorrect:

Uh oh. Remember, in the shape game, if it's a house, then put it here, but if it's a bear, put it here (pointing to appropriate boxes). (Repeat question. If again incorrect, give reminder 1 more time only, then mark as incorrect and continue.)

Okay, let's play. Here is a house; can you put it where it goes? (Rule reminder after every trial.) Here is a bear…

Post-Switch Instructions:

Now we're going to play a different game. We're not going to play the shape game anymore (shake head no). We're going to play the line game. In the line game, if the picture on the card is below the line, it goes here in this box with the house below the line (pointing), and if the picture on the card is above the line, it goes here in this box with the bear above the line (pointing).

(No demonstration trials or rule check.)

Okay, let's play. Here is a house; can you put it where it goes? Here is a bear…

7. Mixed Card Sort

Okay, let's play a (new) game with cards!

Introduction of Stimuli:

I have these boxes here. (Box on E's left has a purple pig with a white background. Box on E's right has a green rabbit with a white background.) This one has a purple pig on it (point to top of box) and this one has a green rabbit on it (point).

Now, look what I have here! I have these cards. (Show purple rabbit and green pig example cards one at a time above boxes in center and then return them to the stack in examiner's hand so they are not showing.)

In this game, we sometimes play the shape game, and we sometimes play the color game. I'm going to show you a card, and I'll say, "Play the shape game" or "Play the color game."

Demonstration Trials:

If I say, "Play the shape game," you play the shape game. In the shape game, all the pigs go here (point) and all the rabbits go here (point). See, here's a pig (hold up in center). It goes in the pig box (put it in). And here's a rabbit (hold up in center). It goes in the rabbit box (put it in).

If I say, "Play the color game," you play the color game. In the color game, all the purple ones go here (point) and all the green ones go here (point). See, here's a purple one (hold up in center). It goes in the purple box (put it in). And here's a green one (hold up in center). It goes in the green box (put it in). Now it's going to be your turn to play this game!

Rule Check (E does not show any test card during check):

If I say, "Play the shape game," you play the shape game. How do you play the shape game?

If Correct:

Very good, that's right.

If Incorrect:

Uh oh. Remember, in the shape game, if it's a pig, then put it here, but if it's a rabbit, put it here (pointing to appropriate boxes). (Repeat question. If again incorrect, give reminder 1 more time only, then mark as incorrect and continue.)

If I say, "play the color game," you play the color game. How do you play the color game?

If Correct:

Very good, that's right.

If Incorrect:

Uh oh. Remember, in the color game, if it's purple, then put it here, but if it's green, put it here (pointing to appropriate boxes). (Repeat question. If again incorrect, give reminder 1 more time only, then mark as incorrect and continue.)

Okay let's play! Play the shape game. Play the color game…

7. Border Card Sort

Okay, let's play a new game with cards!

Introduction of Stimuli:

Look what I have here! I have these cards. (show purple rabbit border and purple rabbit non-border example cards one at a time above boxes in center and then return them to the stack in examiner's hand so they are not showing)

Demonstration Trials:

In this game, you sometimes get a card that has a black border around it just like this one (show a purple rabbit card with a border and draw your finger around the border of the card). If you see cards with a black border, you have to play the color game. Remember, in the color game, purple ones go here and green ones go here (point to respective boxes). This one's purple, so I'm going to put it in this box (put it in).

But if the cards have no black border, like this one (show them a purple rabbit card without a border and draw your finger around the outside of a card to show there's no border), you have to play the shape game. Remember, in the shape game, pigs go here and rabbits go here (point to the respective boxes). This one's a rabbit, so I'm going to put it in this box (put it in).

Rule Check:

So what game do you play if there's a border?

If Correct:

Very good, that's right.

If Incorrect:

Uh oh. Remember, if there's a border, play the color game. If there's no border, play the shape game. (Repeat question. If again incorrect, give reminder 1 more time only, then mark as incorrect and continue.)

What game do you play if there's no border?

If Correct:

Very good, that's right.

If Incorrect:

Uh oh. Remember, if there's a border, play the color game. If there's no border, play the shape game. (Repeat question. If again incorrect, give reminder 1 more time only, then mark as incorrect and continue.)

Okay, let's play! Here's one with a border on it. (Rule reminder after every trial.) Here's one with no border…

8. Reverse Border Card Sort

Now we're going to play a different game. In this game, when you see a card with a border on it, you don't play the color game (shake head no), you play the shape game. Remember, in the shape game, pigs go here and rabbits go here (point to respective boxes).

And when you see a card with no border on it, you don't play the shape game (shake head no), you play the color game. Remember, in the color game, purple ones go here and green ones go here (point to respective boxes).

(No demonstration trials or rule check.)

Okay, let's play! Okay, let's play! Here's one with a border on it. (Rule reminder after every trial.) Here's one with no border…

Appendix 5: Contrastive Negation Training Protocol - Experimental Condition

EC Task 1

E says:
We're going to play a game where I'm going to show you some cards and we are going to find the ones that go together, ok?

E lays out first 6 cards and says: Okay, let's find two that go together. Look at these. What is this one? Good [or Actually…], this is an X. What is this one? This is a Y. Do these go together? Yes [or, Actually…] they go together.

Let's see if we can find another two that go together. *E points to each item of second associate pair in turn and repeats the above.*

E points to each item of non-associate pair in turn and says: Now look at these cards. Hmm. What is this one? It's an X. And what is this one? It's a Y. Do these go together? *No*, they do *not* go together. They are *different*.

Let's play the same game with some new cards. *Procedure is repeated with two remaining sets.*

Session 1	Session 2
Ball/bat, toothpaste/brush, house/shoe	Umbrella/cloud, wheel/car, slippers/bread
Tree/leaf, chair/table, truck/door	Hammer/nail, leaves/rake, shoe/nest
Baby/bottle, lock/key, horse/stamp	Pen/paper, paintbrush/paint, shovel/boat

EC Task 2

E says: Okay, now we are going to look at pictures in this book.

Look at this picture. This one is *round*. Now, look at this one. This one is different. It is *not* round. It's…square. Let's look at the next page.

This is (a/an) ___. Now can you help me find the one that is different, that is not ___? Good. That one is not ___. It is ___. Let's look at the next page…

Target Object, Property or Action	Negation	Irrelevant Object, Property or Action
Round	Box	Round (apple)
Running	Walking	Running (boy)
Hat	Shoe	Hat
Dog	Duck	Dog
Eating	Writing	Child eating
Swinging	Sliding	Child swinging
Bedroom	Kitchen	Bedroom
Cup	Bowl	Cup
House	School	House
Cat	Bird	Cat

EC Task 3

E says: I'm going to show you cards one at a time and sometimes I will say something right and sometimes I will say something wrong, that is silly. I want you to tell me when I say something that is wrong, okay? Let's play.

E shows first card and says: Is this a(n) ___?

On trials in which E provides inaccurate category label if child gives correct response, E says: Good. This is *not* a(n) ___. It's different. It is a(n) ___. *(If child provides incorrect response, E says:* Actually, this not a(n) ___. It's different. It is a(n) ___.)

On trials in which E provides accurate category label, if child gives correct response, E says: Good. This is a(n) ___.

Trial	Target	Label
Discrepant	Apple	Orange
Same	Orange	Orange
Discrepant	Orange	Apple
Same	Apple	Apple
Discrepant	Tree	Flower
Same	Flower	Flower
Same	Tree	Tree
Discrepant	Flower	Tree
Same	Shoe	Shoe
Same	Banana	Banana
Discrepant	Banana	Shoe
Discrepant	Shoe	Banana

EC Task 4

E says: Now we're going to play a new game. Look at this page. Some are hearts and some are different, they are not hearts. I want you to find all the ones that are not hearts and then circle them. Ready?

On every other trial when child circles a shape, E says, Circle the ones that are different; that are not hearts.

After first set complete, E says: Let's play again. Look at this page. Some are squares and some are different, they are not squares. I want you to find all the ones that are different, that are not squares, and circle them. Ready?

After second complete, E says: Let's play again. Look at this page. Some are stars and some are different, they are not stars. I want you to find all the ones that are different, that are not stars, and circle them. Ready?

Instruction	Target (8)	Irrelevant (4 of each)
Circle the hearts	Hearts	Zig zags, stars
Circle the blue ones	Blue dots	Purple dots, yellow dots
Circle the squares	Squares	Triangles, circles

EC Task 5

E says: Okay, now I'm going to tell you about some people in some pictures in this book and ask you some questions about them. *Children presented with photographs of people in various scenarios.*

1. Jane and her mom are at the grocery store. They could get red apples *or* they could get green apples. Jane is about to pick up a red apple when her mom says, "We are not getting the red apples. We're getting different ones." Jane listens to what her mom says. What did Jane's mom say?

2. John is playing with blocks with his friend Wendy. Sometimes they are lining the blocks up in a row or sometimes they are stacking the blocks. John is about to stack more blocks when Wendy says, "Now we are not stacking the blocks. We are doing something different." John listens to what Wendy says. What did Wendy say?

3. Chris wants to go outside. He could put on his boots or he could put on his running shoes. Chris is about to put on his running shoes when his dad says, "Do not put your running shoes on. Put different ones on." Chris listens to what his dad says. What did Chris's dad say?

4. Zach is in the classroom. He could draw on the white paper or he could draw on the blue paper. He is about to draw on the white paper when his teacher says, "Do not to draw on the white paper. Draw on a different one." Zach listens to what his teacher says. What did the teacher say?

5. Daniel is going to the toy store to pick out a stuffed animal. He could get a teddy bear or he could get a puppy. He is about to get the puppy when his brother says, "No, do not get the puppy. Get something different." Daniel listens to what his brother says. What did Daniel's brother say?

Appendix 6: Stimuli Only Protocol - Active Control Condition

AC Task 1

E says:
We're going to play a game where I'm going to show you some cards and we are going to label them, okay?

E lays out first 6 cards (mixed up well to reduce chance that child spontaneously notices related ones) and says: Okay, let's label these cards. What is this one? Good that's a(n) ___. What is this one? Good, that's a(n) ___. *E proceeds in the same way, asking child to label remaining cards in turn.*

After first set is complete, E says: Let's play the same game with some new cards.

Session 1	Session 2
Ball, bat, toothpaste, brush, house, shoe	Umbrella, cloud, wheel, car, slippers, bread
Tree, leaf, chair, table, truck, door	Hammer, nail, leaves, rake, shoe, nest
Baby, bottle, lock, key, horse, stamp	Pen, paper, paintbrush, paint, shovel, boat

AC Task 2

E says: Okay, we are going to look at pictures in this book. I'm going to point a picture and then I want you to help me find another one that I'm looking for. Okay? Let's practice. Look, this one is round. Now look at this one. This one matches. It is also round. Now it's your turn. This is ___. Now look at the other pictures. Which one *matches* and is also (a/an) ___? Good [or Actually…]. This one matches; it is ___. Let's look at the next page…

Target Object, Property or Action	Matching Object, Property or Action	Irrelevant Item
Round (ball)	Round (apple)	Box
Running (girl)	Running (boy)	Walking
Hat	Hat	Shoe
Dog	Dog	Duck
Eating	Child eating	Writing
Swinging	Child swinging	Sliding
Bedroom	Bedroom	Kitchen
Cup	Cup	Bowl
House	House	School
Cat	Cat	Bird

AC Task 3

E says: I'm going to show you cards one at a time and ask you what is on the card. Okay? Let's play. *E shows first card.* What is this?

E waits for child's response and then says: Good, it's a(n) ___.

If child is incorrect, E says: 'Actually, it's a(n) ___.'

Target	Label
Apple	Apple
Orange	Orange
Orange	Orange
Apple	Apple
Tree	Tree
Flower	Flower
Tree	Tree
Flower	Flower
Shoe	Shoe
Banana	Banana
Banana	Banana
Shoe	Shoe

AC Task 4

E says: Now we're going to play a new game. Look at this page. There are lots of hearts. I want you to find all the hearts and circle them. Ready?

On every other trial when child circles a shape, E says, Circle the hearts.

After first set complete, E says: Let's play again. Look at this page. There are lots of blue ones. I want you to find all the blue ones and circle them.

After second set complete, E says: Let's play again. Look at this page. There are lots of squares. I want you to find all the squares and circle them.

Instruction	Target (8)	Irrelevant (4 of each)
Circle the hearts	Hearts	Zig zags, stars
Circle the blue ones	Blue dots	Purple dots, yellow dots
Circle the squares	Squares	Triangles, circles

AC Task 5

E says: Okay, now I'm going to tell you about some people in some pictures in this book and ask you some questions about them. *Children presented with photographs of people in various scenarios.*

1. Jane and her mom are at the grocery store. They could get red apples. There are lots of red ones. Jane is about to pick up a red apple when her mom says, "We are getting the red apples." Jane listens to what her mom says. What did Jane's mom say?

2. John is playing with blocks with his friend Wendy. They are playing a game where they stack the blocks. They can stack them really high. John is about to stack more blocks when Wendy says, "Let's keep stacking the blocks." John listens to what Wendy says. What did Wendy say?

3. Chris wants to go outside. He could put on his running shoes. He likes to wear them. Chris is about to put on his running shoes when his dad says, "Put your running shoes on." Chris listens to what his dad says. What did Chris's dad say?

4. Zach is in the classroom. He could draw a picture on the white paper. There is a lot of it. He is about to draw on the white paper when his teacher says, "Draw on the white paper." Zach listens to what his teacher says. What did the teacher say?

5. Daniel is going to the toy store to pick out a stuffed animal. He could get a teddy bear. There is a brown one on the shelf. He is about to pick the teddy bear when his brother says, "Pick the teddy bear." Daniel listens to what his brother says. What did Daniel's brother say?